7-31-2014

Relating Land Use Factors to Phosphorus Runoff Concentrations within the Northrup Creek Watershed using GIS

Holly Lynne Schulz
The College at Brockport, hschu1@brockport.edu

Relating Land Use Factors to Phosphorus Runoff Concentrations within the Northrup Creek Watershed using GIS

by

Holly Lynne Schulz

A thesis submitted to the Department of Environmental Sciences of The College at Brockport, State University of New York, in partial fulfillment of the requirement for the degree of Masters of Science

July 31, 2014

Relating Land Use Factors to Phosphorus Concentrations within the Northrup Creek Watershed using GIS

Department of Environmental Science and Biology
Thesis Defense by

Holly Lynne Schulz

Date: ______________________

Master's Degree Advisory Committee	Approved	Not Approved
____ Major Advisor	________	________
____ Committee Member	________	________
____ Committee Member	________	________

____ ______________________
Graduate Coordinator Date

____ ______________________
Chairmen Environmental Science and Biology Date

Acknowledgements

I'd like to thank my family, friends, professors, and loving fiancé for supporting me through the entire process of this thesis. Special thanks Dr. Mark Noll, Dr. Joseph Makarewiz, Dr. James Zollweg, and Dr. Paul Richards for all the time, guidance and advice they have provided me with throughout these past years.

Table of Contents

List of Tables

List of Figures

List of Appendices

Relating Land Use Factors to Total Phosphorus Runoff Concentrations within the Northrup Creek Watershed using GIS

Abstract

Efficiently and accurately measuring storm event non-point source pollution contributing to streams and lakes from various land uses is one of the more difficult tasks in watershed management. Many physical variables go into the input and export of nutrients, making it difficult to identify source contamination areas that may lead to reduced stream quality and increased eutropication of water bodies. A major drawback to rehabilitating these impacted streams is being able to easily identify the specific land use types or source areas. Designing a simple method with adequate precision and consistent outcomes to help identify sources of nutrient export would increase efforts to remediate these locations as well increase efficiency. This study evaluates (1) the use of geographical information system (GIS) and stream segmentation to identify the correlation between land use variables and total phosphorus concentrations in storm events, (2) the ability of land use variables in predicting storm event runoff phosphorus concentrations, and (3) identifies specific high and low risk areas of phosphorus contribution throughout Northrup Creek, a small watershed in Rochester, NY.

Correlation and modeling results show that an increase in vegetative lands, including forested, shrub, and grasslands, that are in close proximity to the creek have a tendency to decrease the amount of total phosphorus (TP) in runoff stormwater. Increases in low residential lands, including barren and open lands uses, have a tendency to decrease the amount of TP in runoff stormwater as well. Two variable

groupings, individual land uses and individual land uses 90 meters from the creek, have the strongest correlations with total phosphorus runoff concentrations during storm events.

Segmental risk ranking results suggest Segments 3 and 8 of the Northrup Creek Watershed study have the highest average storm event TP runoff concentrations and thus pose the greatest risk to phosphorus contribution to the creek. Noted specific land uses identified in Segment 3 and 8 include a public golf course, barren developmental lands, and inputs from the Erie Canal.

Additional physical processes not analyzed were have found to influence the runoff concentrations calculated within the study. Non-uniform storm rainfall duration and rates coupled with antecedent soil moisture content throughout the segments are very probable influences on the amount of phosphorus entering the creek at the various segments. A lower runoff residence time created by ponds and the low sloping areas is suggested to have aided in the settling of particulate phosphorus to the creek bed between segments, influencing a decrease of runoff concentrations during storm events. Lastly, the introduction of artifact phosphorus back into the stream system, created by the former STP, through turbid creek conditions is suggested to increase of TP concentrations downstream.

Introduction

<u>Phosphorus and its effect on the ecosystem</u>

Phosphorus is an important nutrient for all life and often the limiting nutrient responsible for plant growth in freshwater systems (Schindler, 1971, Bennett, 2001, and Liu, 2008). It is the 11th most abundant element, and exists in rocks, soils, water, and all organic matter on earth. The natural cycling of phosphorus is a slow process which includes absorption and output through plant and animal life. An increase in human activities has created an imbalance in the natural phosphorus cycle creating ecological issues including decreases in water clarity and increase risk for eutrophication (Caraco, 1995).

Phosphorus within the natural environment can be divided into either particulate or dissolved form. Particulate phosphorus (PP) occurs as either organic or inorganic forms which are separated from water through filtration. Particulate phosphorus includes suspended forms of bacteria, large zooplankton, clays, detritus, and other plant material. Total dissolved phosphorus (TDP) is further separated into soluble reactive phosphorus (SRP) and soluble unreactive phosphorus (SUP). Soluble reactive phosphorus, or orthophospate, is the main dissolved form of phosphorus readily accessible to aquatic plants and is largely linked to the ecological risk related with nuisance algal growth in rivers during times of low flows (Jarvie *et al.*, 2006). Soluble unreactive phosphorus is unreactive to phosphorus reagents and is mainly organic but can contain inorganic chains called polyphosphates. Total phosphorus (TP) is the summation of PP, SRP and SUP. Measuring both SRP and TP can be used to determine the amount of eutropication in a freshwater body. Since phosphorus continually changes form, many scientists use TP to determine its bioavailability for algae and plants (Minnesota Pollution Control Agency, 2007).

TP can be notably higher during storm events; however, SRP varies little between runoff events and baseflow due to dilution according to studies by Ellison and Brett (2005) and Jarvie (2006). This increase can be identified as a result of several factors including land use changes (such as addition in residential and agricultural developments, roads and other impermeable surfaces due to construction of commercialized locations), and the location of septic tanks, storm water outfalls, construction activities, and sewage treatment plants upstream.

<u>Land Use types and their effect on Phosphorus Loadings</u>

Human alteration of the landscape over the past century can be related to the downfall of water quality in many streams across the country (Bartsch, 1970). Beginning in the 1970s, research into how land use influences the water quality water bodies gained popularity as an increasing number of eutrophic lakes and waterways emerged (Burton, 1979, Cooke, 1973, Dillon, 1975, Gaynor, 1979, and Smith, 1978). Experimentation with phosphorus introduction to Lake-227 in Ontario, Canada, concluded that phosphorus is often the limiting nutrient to plant production in an aquatic ecosystem (Schindler, 1974). This finding created a public uproar on detergent loading into streams and bodies of water and led to the self-realization that human actions do jeopardize water quality among streams, rivers and lakes. A compilation of studies aimed towards nutrient export in North America and general land use was summarized by Beaulac and Reckhow (1982). Row crop and urban land use types show exporting in highest amounts of phosphorus while forest exports the lowest.

In recent years, evaluations of phosphorus exports during storm and non-storm events has been developed and compared to land use using GIS, helping to confirm the effects of specific land uses types on water quality (Hiscock *et al.* 2003, Kovacs and Honti, 2008, and Bennion *et al.* 2005). This application of GIS is extraordinarily beneficial in comparing and ranking spatial data to the potential environmental risks of water quality.

Agriculture

Being an area abundant in farming production, much of the landscape across New York is dominated by agricultural and crop land uses. Close to one quarter of New York's land area is utilized as agricultural land, and although farmland has been declining in recent years, the state continues to maintain its high rank in production of foods such as apples, grapes, corn, dairy, and other commodities (New York State Comptroller, 2010). With a high amount of land dedicated to growing comes the risk of soil erosion and non-point source pollution in the form of stormwater runoff of excess nutrients, fertilizers, and other contaminates. Although farms have been residing in the watersheds for nearly 250 years and have provided food and other needs to nearby inhabitant and businesses, they are considered a major source of non-point source pollutants, creating unhealthy effects towards creeks, rivers and other bodies of water. Several studies have found that soil erosion (created by crop stripping), excess amounts of applied fertilizer and manure in areas of dairy and livestock farms, row crops and other high intensity agricultural setting contribute to a higher level of phosphorus in storm water runoff (Carpenter *et al*. 1998, Sharply, 1999, Haygarth, 2005, Vadas, 2008, Barbosa, 2009, Kato, 2009, and Withers, 2009).

Cropland and pasture areas, especially those that are in close proximity to streams, jeopardize the health of the runoff water flow with high nutrient loading. In a study of a mixed land use watershed consisting of wooded, cultivated and pasture land uses, results showed that near-stream surface runoff (60m away from stream) accounts for much of the high stream flow P concentrations (Sharply, 1999).

New developments in incorporating Best Management Practices (BMPs) in agricultural lands help reduce the phosphorus, soil and other nutrient load levels and improve the health of many streams. An example of such was a Graywood Gully, a small sub-watershed adjacent to Conesus Lake in NY, containing 74% agricultural land use. Graywood Gully was subjected to BMP such as improved manure application processes, installation of sub-surface drainage and limitation of access of livestock through potiental high runoff locations. As a result, nuisance algae and *E.coli* loading has decreased in Conesus Lake significantly (Simon and Makarewicz, 2009; Makarewicz *et al.* 2009). Although, even after BMPs are emplaced and flux phosphorus input in runoff is decreased, high levels of phosphorus concentrations can resurface in settled sediments located at the bottom of streams through oxidation and reduction processes and the natural stirring up of channeled water, causing a lake or bodied water to remain eutrophic (Carpenter, 2005).

Urban/Suburban

Imperviousness

Imperviousness is the inability of a surface to allow infiltration and is an important factor relating to the amount of storm water runoff. Areas having impervious features, such as pavement, rooftops and other manmade planes, increase the amount of runoff and decrease the recharge of groundwater to subsoil. The amount of impervious land within a watershed can increase runoff volumes exponentially and is a main cause of higher loading within rural and urban residential areas (Soranno, 1996, Dietz, 2008, Withers 2009). An area with as little as 10% impervious cover can have an effect on stream stability, resulting in flooding and higher bank erosion (Schueler, 1994). Several residential and urban factors can fall under high impervious surfaces, such as roads, roofs and driveways.

Roads

Roads serve a vital role to human society, but contribute large impervious surfaces within a watershed. Runoff contained on a high impervious road can be saturated with high amounts of sediment particulates, nutrients and other chemicals associated with vehicles. In one study monitoring TP in different types of urban uses, collected storm runoff from residential and industrial streets recorded average values of TP ranging from 0.94-1.50 mg/l (Bannerman, 1993). The amount of traffic volume, the type of nearby land uses and pervious dry periods can determine the amount of solid particle loading to a road (Miguntanna, 2010) and can result in higher P and other nutrient concentrations when saturated with precipitation runoff from storm events.

Residential Factors

According to the U.S. Census Bureau, in 2000, half of the United States population lived in suburban areas (Hobbs and Stoops, 2002). With population expanding, the need for homes and communities has increased resulting in high residential development rates across the country. Many forests have been cleared and unused agricultural lands have been converted to residential neighborhoods. Previous grasslands and pastures are transformed into asphalt and concrete surfaces, while toppled trees and excavated lands are exposed to erosion, making way for lawns and backyards. This change of land use can eventually be seen in the chemical composition of waters in nearby streams as they increase in soil sedimentation, nutrients and household chemicals.

Although creating more runoff saturated with heavy metals, residential roofs can release a small amount of phosphorus due to atmospheric deposition (Bannerman, 1993). Gravel type roofs tend to retain TP better after a storm event as opposed to polyester or tile roofs (Zorbrist, 2000). It is suggested to residential homeowners to direct roof runoff into gutters that are piped down into the ground to allow for the natural filtration of phosphorus.

Used to park and wash cars, driveways are likely to be one of the larger promoters of phosphorus loading in a residential area (Bannerman, 1993). Homeowners who wash their cars upon their driveways, as opposed to their lawns or commercial carwashes, increase the risk of phosphorus loading, allowing soaps and detergents to be carried away to nearby stormwater catchments or drainage ditches. According to a study conducted in the city of Federal Way, Washington, 11% of homeowners washed their car once a week and 38% wash their cars on their driveways. The same study demonstrated that TP concentrations from set up car washing catch basins ranged from 0.75 mg/L – 6.3 mg/L, proving that residential car washing clearly has a negative effect in phosphorus loadings (Smith and Shilley, 2009). In terms of material, Asphalt driveways, compared to paved and stone driveways, are the most prone to low infiltration rates, higher runoff discharge, and greater phosphorus concentrations (Gilber, 2006).

The greatest influence of maximum phosphorus export from residential neighborhoods is the maintenance and care of lawns and gardens. In the United States, approximately 25-40 million acres of land has been converted to lawns (Robbins, 2003), and with this change comes the need to uphold the health of these residential lands. Most homeowners do not know the phosphorus content of the fertilizers they use on their lawns (Morris and Traxler, 1996), nor do they take soil samples to take note of how much, if any, fertilizer is needed (Schueler, 1999a).

About 35% of the population in the United States over-fertilizes their lawns (Schueler, 1999b) and with tons used each year, the amount of fertilizer applied to homes is about equivalent to the rates of application for row crops (Barth, 1995). During significant rainfall events, loading of phosphorus off lawns can reach critical levels in runoff (Bannerman, 1993).

Many towns often harbor golf courses among parks and other recreational vicinities within residential areas. As many typical golf courses contain a stream or creek within their premises to uphold the natural and pristine looks of the course, the risk of these water bodies many be in jeopardy due to nutrient loadings caused by fertilizer runoff. In order to maintain the healthy look of a golf course, owners and managers often apply large amounts of fertilizers to greens and fairways. Excess fertilizer often ends up in storm runoff where it flows into the streams after a large rainfall. A study shows that TP annual export rates within four streams flowing out of two golf courses were on average two times greater than those taken from ten undeveloped, forested reference streams (Winter and Dillon, 2006). Similar research was conducted on a brook with a forested area upstream from a golf course. Average TP concentrations from the forested discharge basin were between 0.0072 and 0.145 mg/l while concentrations from the discharge downstream of the golf course were 0.133 and 3.04 mg/l (Kunimatsu *et al.* 1999). Development of vegetative buffer strips and manmade wetlands within golf courses slightly eases the amount of runoff and P loadings to the streams (Kohler *et al.* 2004 and Moss *et al.* 2005); however, not all golf courses contain these buffers to help manage nutrient runoff.

Along with fertilizers, pet waste may also contribute to higher concentrations of P in soil and stormwater especially in highly concentrated residential areas. With many believing pet excrement is not a large water quality issue, pet owners are reluctant to clean up after their pets waste due to sanitary issue or just plain negligence (Swann, 1999).

Commercial and Industrial Lands

As the rate of residential areas increase, the need for commercial and industrial infrastructure also continues to expand. Super markets, malls, businesses and factories include large impervious surfaces such as parking lots and roof surfaces, which can contribute to higher quantities of runoff and pollutant loading. Phosphorus within the atmosphere deposits on the top of buildings and sediment carried around by vehicles are just a few ways phosphorus can enter a commercial or industrial setting. Runoff from industrial roads connecting businesses and residential areas together have been found to contain the highest concentration of phosphorus when compared to arterial and feeder streets (Bannerman, 1993). Although typically not as high as residential areas, phosphorus concentrations within runoff from commercial and industrial areas do exist due to higher traffic areas.

Storm sewers and outfalls

The ability to monitor and maintain good water quality within a watershed is dire to the ecology and health of a watershed. Many cities, towns and neighborhoods empty their storm water systems through outfalls into a nearby river or stream without treatment, leading to higher concentrations of nutrients, metals and toxic pollutants.

The chains of sewer systems within these urban/suburban areas are called Municipal Separate Storm Sewer Systems, or MS4, and contain elements such as underground pipelines, drains, ditches, manholes, and catch basins. Today, the Clean Water Act requires all small regulated MS4 within and outside of urban areas obtain a general State Pollutant Discharge Elimination System (SPDES) permit, which control water pollution by regulating point sources that discharge pollutants into nearby waters. Each regulated MS4 is required to develop and apply a stormwater management program (SWPM) to reduce the contamination of stormwater runoff.

Another way to eliminate contamination to a stream is by establishing a sewage treatment plant, or STP. The purpose of an STP is to remove organics, solids and pathogenic organisms produced from the domestic or stormwater and change them from a complex makeup to stable minerals or organics that can be compatible with the environment.

Rural Septic Systems

Unlike urban areas that have treatment plants and sanitary systems, smaller populated, rural areas rely on septic tanks in order to remove waste water created by sewage, detergents, and other household chemical inputs. Water that is released by a septic tank is sent through drainage fields, where soil and gravel act as a natural filter in removing bacteria and nutrients. After storm events, soils around septic tank drainage fields can become saturated with water and produce runoff on the surface and within infiltrated subsoils. These septic systems are able to act as multiple point sources and can generate a higher concentration and loads of nutrients such as phosphorus within the runoff (Jarvie *et al.*, 2010). Low flows coupled with heavy clay soils as well as stream areas near direct septic pipe outputs are shown to produce higher TP, SRP and TDP concentrations (Withers *et al.*, 2011).

Forest and Canopy Impact

The abundance of trees and canopy cover allows for interception of precipitation, leading to a reduction in throughfall and less runoff on the surface (Cochran, 2005). The Hubbard Brook Ecosystem Study conducted between October 9th, 1967 and May 31st, 1969, in New Hampshire's White Mountains, experimented with an undisturbed forested watershed (13.2 ha) and a cut (but left in place) watershed (15.6 ha). The deforested watershed produced 26% more runoff and increased the loss of particulate phosphorus twelve times more than the undisturbed watershed due to increases of water velocities and erosion (Hobbie and Likens, 1973). The same experiment also showed that removal of root surfaces that were able to uptake nutrients allowed for greater nutrient loading in the increased amount of leached runoff (Bormann *et al.* 1968). The higher amount of tree canopy and reduced deforestation allows for less erosion of the soil due to raindrop impact and a lower potential for soil nutrient runoff (Bullard, 1966). Ultimately, the risk of export of nutrients in receiving waters typically decreases as you increase in the percentage of forest throughout a watershed (Wickham and Wade, 2002).

Trees and vegetated cover can reduce the amount of precipitation reaching the surface, but they also highly influence the fluid mechanics of rainfall that does make it to the ground. Typically, the higher amount of tree canopy and reduced deforestation allows for less erosion of the soil due to raindrop impact and a lower potential for soil nutrient runoff. Roots from vegetation slow up runoff flow and hold soil together more firmly allowing for lower amounts of erosion (Bullard, 1966).

Wetlands

Wetlands are described as areas of transition between aquatic ecosystems and upland areas, which contain saturated soil conditions due to the water table being at or near the surface. They are one of our planets' most valuable natural resources as they serve many different positive functions for their environments. Ecologically, wetlands provide homes and breeding grounds for birds, amphibians, fish species and other animals that reside in them, and can also be used for human recreation. In a physical aquatic setting, wetlands are a source of flood control for heavy runoff storm events. They often retain sediment and can be used as a source of erosion control. In addition, wetland soils act as a natural filter as they serve as sinks for storm runoff nutrients, such as phosphorus and nitrogen, and help remove them from the aquatic system (Dunne, 2007, Kadlic, 2005, Knight, 2002, and Tonderski, 2005). One study suggests that the presence of wetlands in upstream features results in an increase of phosphorus concentrations within downstream lakes due to reducing water inflow to downstream lakes (Zhang *et al*, 2012).

Wetlands are often classified by their values, functions and benefits, from plant and animal habitats to pollution and erosion control. The National Wetland Inventory (NWI) classifies wetland based on a hierarchical classification scheme of system (Marine, Estuarine and Riverine), subsystem (sub-tidal, intertidal, and tidal), class (Aquatic bed, rocky shore, unconsolidated shore, unconsolidated bottom, scrub-shrub, forested wetlands, and emergent wetlands), subclass, Water Modifier, and Special Modifiers.

<u>Soils Effect on Phosphorus Loading</u>

From composition and texture to permeability and porosity, soils play an important role in water flow and quality. Soils serve as retention spaces for water, nutrients, and minerals, as well as act as natural filters for contaminates and pollutants. Hydraulic conductivity, or ease at which water can pass through a soil, is one of the major influences on the imperviousness of a soil, and directly contributes to amount of runoff within an area. Soils can be classified into compositions based on soil texture, size, and hydraulic conductivity: clays, silts, or sands. Clays are finest in size and contain the smallest pores between particles resulting in the lowest permeability. Areas with abundant amounts of clay soils typically are poorly irrigated and have high runoff rates that are conducive to increased erosion and P losses (Turtola, 1995). Silts are coarser and contain larger pores and fracture space than clays. The most permeable soils are sands and gravels, which can store the highest content of water.

Along with texture and type, soil thickness and depth are other factors that control the potential of runoff. In general, an increase of soil thickness paired with high permeability results in higher amount of storage and infiltration of stormwater, decreasing the amount of surface runoff. Vulnerable to human activities, subsurface soils tend to store more P, while P within soil tends to decrease with an increase in soil depth (Reddy, 1998).

Developed by the Natural Resources Conservation Service (NRCS) of the United States Department of Agriculture (USDA), soil hydrologic grouping classifies soils into four separate categories according to the rate of infiltration and transmission during prolonged wettings. Hydrologic soil groups A and B are permeable soil types, allowing lower stormwater runoff potential. Hydrologic soil groups C and D are more impermeable soil types, allowing higher stormwater runoff potential. Additional information on the USDA's National Engineering Handbook classification of hydrologic soil groups is provided in Appendix 1.

When used with land use type, the soil hydrologic group can determine the curve number, or runoff potential, of an area. The higher the curve number of an area, the greater the imperviousness and runoff potential it has. An increase in runoff can lead to higher erosion rates and sediment loading and can ultimately by related to higher amounts of PP loadings in water.

Stressed Stream Analysis and Stream Segmentation

First developed by Makarewicz and Lewis (1999), stressed stream analysis is an integrated approach to targeting, assessing and quantifying individual sources of pollution within a watershed. Stressed stream analysis uses a stream segmentation method, which divides a watershed up into several smaller sub-watersheds, in order to more easily identify source pollution areas, then ranks these sub-watersheds based off concentrations and loading of pollutants found within them. Used in watersheds within Sodus Bay, NY, and Conesus Lake, NY, stressed stream analysis is an effective and inexpensive way to detect source areas of high phosphorous concentrations and loadings (Makarewicz *et al* 1993*;* Simon and Makarewicz, 2005).

Previous Studies

Stressed stream research and methods have been applied on Northrup and Larkin Creek, by Monroe County, NY, by measuring storm induced runoff and baseflow along several divided areas among the watershed. Phosphorus concentrations were monitored throughout various sample points within each divided area during baseflow and storm events. Residential development and land use changes were then correlated with phosphorus concentrations to show that recent or active developments within the watersheds could be a contributing factor to higher phosphorus concentrations. In conclusion, further research into land use and phosphorus concentrations was recommended by Monroe County on the Northrup Creek watershed.

A study of the chemical analysis and non-point and point source nutrient loading was performed on the Northrup Creek Watershed by Makarewicz and Lewis (1990). Results indicated that the Spencerport Sewage Treatment Plant (STP) attributed about 56.4% of the total annual average daily phosphorus loading to Northrup Creek. Also noted was that the Spencerport STP only performed secondary treatment of sewage and therefore did not remove phosphorus from the sewage. This identified Spencerport STP as a major point source of phosphorus loading to Northrup Creek. Currently, the Spencerport STP is no longer in operation due to its closure in 2008. Non-point source evaluation of selected agricultural areas in the Northrup Creek Watershed during base flow resulted in no increase in concentration of nutrients.

Water Quality Standards and Current Methodologies

The New York State Department of Environmental Conservation (NYSDEC) has not yet developed a quantitative standard for phosphorus in water. The current NYSDEC water quality standard for phosphorus states that no phosphorus should be added in "amounts that will result in growths of algae, weeds and slimes that will impair the waters for their best usages" (NYSDEC, 2008). From a federal standpoint, the U.S. EPA has established that a stream entering a lake or reservoir should not contain more than 0.05 mg L^{-1} of TP; and in streams where discharge is not directly into lakes or reservoirs TP should not exceed 0.1 mg L^{-1} (Sparks 2003).

The Waterbody Inventory and Priority Waterbody List (WI/PWL) and 303(d) List of Impaired Waters are databases developed by the NYSDEC that characterize water quality in New York State waterbodies, including the their level of impairment and stress caused by nutrients, such as phosphorus. Methodologies used by the NYSDEC to aid in determining the effect of nutrients on waterbodies and develop these lists include the use of biomonitoring data developed using aquatic macroinvertebrates analyses. The Nutrient Biotic Index (NBI) adopted by the NYSDEC measures nutrient enrichment of a stream based on the tolerance of macroinvertebrates to nutrient pollution (Smith, 2007).

The NYSDEC has worked with several communities to study the influence of land use characteristics on non-point source phosphorus loading to impaired waterbodies. Total daily maximum loads (TMDL) have been developed based of these studies to determine the specific maximum amount of phosphorus that a waterbody can receive and still meet water quality standards. In order to meet the TMDL and reduce the amount of phosphorus in waterbodies, the NYSDEC have issued permits that requires municipalities and businesses to implement best management practices into their stormwater management programs (SWMPs). NYSDEC does not require municipalities and businesses to sample or test their phosphorus water qualities; however, with an aim to develop and implement a Nutrient Standards Plan (NSP) with the upcoming years, the NYSDEC criteria for measuring phosphorus variations and reductions in an impaired waterbody may change (NYSDEC, 2011).

In addition, under the NYSDEC SPDES MS4 General Permit, municipalities and businesses that occupy watersheds that discharge to an impaired waterbody without a TMDL study are required to develop modeling data showing no increase of pollutants when greater than an acre of land is disturbed. Municipalities and businesses that occupy watersheds that discharge to an impaired waterbody that have TMDL or are under a watershed improvement strategy are required to develop modeling data that shows no net increase of pollutants at any time. If there is an increase in the pollutants, the municipality or business must evaluate their BMPs and modify their Storm Water Management Plan (SWMP) to reduce the pollutant loading to meet the waste load allocation.

Objective

Loading prediction models that use GIS applications, such as ArcView Generalized Watershed Loading Function (AVGWLF), have been developed to evaluate the sources of phosphorus loading in streams with little to no monitoring data (Evans *et al*, 2002); however, these types of models use event mean concentrations and land uses to predict phosphorus fluxes (Haith *et al*, 1992). Monitoring data from the specific impaired waterbody in question would allow for an increase in accuracy when determining phosphorus loading data. In addition, these GIS based models are able to determine which land uses influences phosphorus loading, rather than pinpoint the areas of high and low risk of phosphorus contribution within a watershed.

Using the aid of GIS based models, TMDL is being developed for only a select number of impaired waterbodies in New York. The majority of impaired waterbodies in New York do not have TMDLs or are undergoing watershed improvement strategies. As more TMDLs and watershed improvement strategies develop, hundreds of municipalities and businesses that have a NYSDEC MS4 General Permit, and are located in an area having a TMDL or watershed improvement strategy, will need to have the resources to develop the require modeling to show no increase in the pollutant of concern (POC). Efforts to develop and implement a model can be time consuming and costly. Entities covered under MS4 General Permit in a TMDL or watershed improvement strategy area may not contribute POCs but are still required to spend money and time to develop and maintain models. These requirements of having numerous municipalities and businesses across large areas develop and evaluate model data may be an effective way of aiding to reduce POC loading to a waterbody over a long period of time; however, it is an inefficient method that requires all entities in the waterbody watershed to spend their valuable resources for an issue that may only apply to specific entities.

Rather than develop TMDL evaluation studies for impaired waterbodies and have all entities under the impaired watershed sacrifice their resources to reduce phosphorus loading, regulating bodies should develop stream segment studies that are able to target specific high risk locations of phosphorus contribution. The objective of this study is to investigate and develop a simple technique for identifying specific land uses and areas that have a high risk of contributing phosphorus through non-point source runoff within a creek system during storm events using GIS, stream segmentation analysis, and phosphorus concentrations collected by grab samples.

Similar to the Makarewicz and Lewis study, stressed stream analysis can be used on the Northrup Creek watershed to categorize source areas creating high phosphorus concentrations within the creek waters. By dividing the watershed up into several sub-watersheds separated by roadways, ARCGIS, a geospatial information system program, can locate the percent and acreage of each land use and quantity of contribution factors (land use variables) within each segment. These quantities can determine which segments have potentially high and low risks of phosphorus runoff during storm events based on the evidence of previous studies. Grab samples can be collected during storm events at each selected roadway within the watershed to get a representative TP concentration within the creek for each segment and contributing upstream segments. Collection of stream flow data and measurement of stage height at each of these roadways can be used to produce rating curves to determine TP loading data. TP runoff (TPr) concentration from each segment would be calculated based on upstream and downstream loadings. TPr concentrations determined for each segment can be compared to the quantity of each land use variable within each segment. This will determine which land use variables would have the greatest overall influence on the increases of TPr concentration in the creek.

Using the TPr concentration values of each storm event and land use variable for each respective segment, a linear regression analysis can be utilized to produce a site specific model to predict TPr concentrations. Evaluating TPr concentrations also provides representative data of the quantity of phosphorus removed or absorbed from land during storm events within each segment. This study will identify high and low risk segments and land uses variables within Northrup Creek through analysis of TPr concentrations. The study will also model TPr concentration for each storm event and will provide an understanding of how to better predict the amount of phosphorus entering Northrup Creek.

Study Area

Northrup Creek is a 64 km^2 sub-watershed system within watershed 04130001 defined by the USGS. Northrup Creek drains into Long Pond, a hypereutrophic pond found in the town of North Greece adjacent to Lake Ontario, in Monroe County, NY (43º1'N, 77º4' S) (Figure 1). Northrup Creek originates in the town of Ogden, near the village of Spencerport, and flows northward through the towns of Parma and Greece, where it discharges into Long Pond, which is identified by the NYSDEC as 303(d) impaired water body requiring a TMDL for phosphorus. The Northrup Creek watershed is bounded by the Larkin Creek watershed to its east, the Buttonwood Creek watershed to its west, the Little and Black Creek watersheds to the south, and Lake Ontario to its north. The width of the watershed is approximately 10 km at it's widest and the length is approximately 26 km. In the past, the amount of SRP and TP loading to Long Pong has been moderately high due to point source and non-point source storm runoff drainage and baseflow of excess nutrients from the Northrup Creek watershed associated with the Spencerport STP (Makarewicz, 1989).

Methods

Field Methods

Stream discharge values were used at each of the sampling locations in order to evaluate TPr during storm events. To determine the discharge of each sample location at a given collection time, rating curves comparing stage height and discharge were developed using stream gaging techniques.

At each sample site, cross-sectional measurements of stream depth, width and velocity were taken at various times of flow. Width was calculated using a meter-based tape measure, and was laid out perpendicularly to the stream with right angles at the banks. Depth in meters was calculated using a wading rod. Stream velocities in meters per second were determined with a Marsh-McBirney Flow-Mate 2000 portable flow meter attached to the wading rod. Since the stream depth measurements were less than a meter, the velocity sensor was set to measure values at 60% of the depth. Using values of depth, width, and velocity, discharge was calculated using Equation 1. All discharges were then added up to determine the total discharge of the stream at that particular time.

Equation 1: $Qn = [(D(n) – D(n-1))/2 + (D(n+1) – D(n))/2] * V(n) * DP(n)$

Where:

n = point number sample

Qn = Discharge at n point (m^3/sec)

D = width from water edge (m)

V = velocity (m^2/sec)

DP = depth (m)

The surface height of the stream was determined by marking a specific location on a bridge or covert underpass at each of the sites. The drop down height measure between the marking and water surface provided a representation change in water levels, and would be a viable substitution for staff height.

Gauging measurements were taken at high and low flows to increase the working range of the data. At least five gauging measurements per sampling location were used to construct a rating curve for each sample location. A USGS gauging station located at the segment three sampling point provided additional gauging measurements for segment three's rating curve. An exponential regression line was used based off the plotted drop down height and discharge. Rating curves and corresponding discharge equations for the sampling points are provided in Appendix 2.

TPr for the sampling points during storm events was calculated using Equation 2. TPr was unable to be calculated in instances where discharge upstream was greater than discharge downstream.

Equation 2: TPr = (Ldown – Lup)/(Qdown-Qup)

Where:

TPr = Net change in total phosphorus runoff concentration (µg/L)

Lup = Upstream total phosphorus loading (µg/sec)

Ldown = Downstream total phosphorus loading (µg/sec)

Qdown = Downstream discharge (L/sec)

Qup = Upstream discharge (L/sec)

Raw sample data showing TP, discharge, measurement values, TP loading and TPr values for each sampling event is provided in Appendix 3. The TP concentration value in this study is representative of TP within the creek during the time of rain fall and includes storm runoff discharge, groundwater infiltration discharge, and base flow. The TPr concentration value in this study is representative of TP entering the creek through runoff discharges and groundwater infiltration. If the discharge values of upstream sampling points are greater than that of discharge values of downstream sampling points, the TPr concentrations were not calculated (N/A). This indicates that there was a loss of discharge throughout the segment and phosphorus could have settled, stored, or removed through absorption within that segment.

Sampling Methods

Water

Sampling methods for this research were based on Standard Methods section 1060B – Collection of Samples (American Public Health Association *et al*, 2005). Grab samples were obtained during storm events using plastic, 500mL bottles that were previously cleaned in a 10% hydrochloric bath. A polyethylene cup with an extension was used to collect water in the middle of the channel and away from the banks for accurate sampling. The cup and bottles were rinsed with stream water before a collection to prevent contamination. Bottles were labeled with the date and location then placed in a cooler with ice. Drop down height was immediately measured and recorded following the sample collection for stream discharge calculation. A duplicate sample was taken at one of the eleven sites, along with the primary sample for comparison of analytical results, in order to ensure data quality.

Precipitation

Significant storm events with an average precipitation measurment over 3.8 mm were designated for water sample collection due to the large amount of runoff provided. Four rain gauges established by Weatherbug around the watershed were used to measure this specific amount. These locations are Oliver Middle School, in Brockport, NY, Quest Elementary, in Hilton, NY, Parklands Elementary, in Greece, NY, and Gate-Chili High School, in Gates, NY (Figure 2). Since the first flush of runoff contain the most accurate and appropriate measurement of TP concentration within a storm runoff event,the collection of samples began within an hour after initial precipitation.

Laboratory Preparation

Preservation methods for this research were based off the Standard Methods section 1060B – Collection of Samples and 1060C – Sample Storage and Preservation (American Public Health Association *et al*, 2005). Grab samples were placed into 50mL plastic tubes that had been previously disinfection in a 10% HCl bath. 1mL of 5N sulfuric acid (H_2SO_4) was added to the TP samples. All samples were then stored in a refrigerator at 5.5ºC where they awaited further processing.

Analytic Laboratory Methods

TP samples were digested using the Standard Methods Ascorbic Acid Method, Method 4500-PE (American Public Health Association, 2005). Before digestion, 1 drop of phenothaline was added to the TP samples. Digestion occured for three hours at 95ºC using a DigiPREP Jr. heater. TP concentration in µg/L were attained using a Beckman DU640 spectrometer set at 880nm wavelength. Sulfuric acid (H_2SO_4), potassium antimonyl tartrate, ammonium molybdate, and ascorbic acid were combined to form a reagent. The reagent was then added to the digested sample as well as the 0µg, 25µg, 50µg, 100µg, 200µg, and 500µg standards developed from a stock phosphate solution.

GIS Methods

Sub-watershed segments and respective land use data was determined using ArcMap version 9.3, a Geographic Information System (GIS) type programing. GIS land use data was retrieved and analyzed in March, 2011. The National Land Cover Database (NLCD) presented by United States Geological Survey (USGS) provided land use cover data for 2006, the most recent available data at the time of analysis. The NLCD 2006 land cover class descriptions are presented in Appendix 4.

Other land characteristics used in ArcMap were retrieved from online rapositorys, such as Cornell University Geospatial Information Repository (CUGIR, 2011), the Multi-Resolution Land Characteristics Consortium (MRLC, 2011), and New York State GIS Clearinghouse (2011). The Monroe County GIS department provided septic tank data. Stormwater outfall data was observed using the Monroe County GIS department mapper. Division of each stream segment, including the total watershed itself, was determined by using the watershed delination feature within the USGS's Stream Stats online program. Each subwatershed was delineated based of the eleven sampling points.

Several tools were used in ArcMap to help aid in comparing land attributes to water sample data. The Spatial Analyst was used to cut and fit raster data with the shape of each sub-watershed segment. Precipitation values across the watershed were determined using density weighting, which averages the precipitation values of the four sample points across an area, within the Spatial Analyst toolbar. Using the

Analysis Tool, a 90m stream buffer of the stream system was developed using the proximity feature called buffer within the Analysis Tools.

The attribute table associated with each shape, polygon, and raster data set were used to record specific information about each land use feature, such as units of each type of land use, stream and road distances, values of precipitation and elevation, and number of septic tanks within each sub-watershed. Percentages and areas of each land use along with total amount of each variable in the sub-watersheds were recorded.

Statistical Methods

Normality of Data

Assumptions for correlation and linear regression modeling require data to have an approximate normal distribution. TPr concentrations and land use values were tested for normal distribution using the Shapiro-Wilk test. Outliers in the data were removed to normalize the data when appropriate.

Correlation

IBM's SPSS 9.0 statistical program was used to correlate values of TPr concentration to land use factor percentages, area and values. Correlation matrices between TPr concentration values and land use values were developed using the Pearson correlation coefficient for parametric data and the Spearman's Rho correlation coefficient for non-parametric data. All correlation tests were conducted using a two-tailed test of significance with a $\rho \leq 0.05$ significance level. Raw correlation data between TPr concentrations and the land use variables for the storm events and the average of the storm events is shown in Appendix 9.

Linear Modeling

A stepwise multiple linear regression analysis was used to determine which land use factors had a significant influence on TPr concentrations. Stepping method criteria included using a probability of F with an entry significant of $F \leq 0.05$ and a removal significance of $F \geq 0.1$. A Durbin-Watson statistic was used to test the independence of each of the observations entered in the stepwise regression test. An ANOVA test with a significance level of $\rho \leq 0.05$ was used to determine whether the land use factors were unrelated (null hypothesis=Ho) or related (alternate hypothesis=Ha) the TPr concentrations in each stepwise model. To meet the basic assumption of a linear regression, only parametric land use variables were entered into the stepwise linear regression.

Segmental Ranking

Segments were ranked from largest to smallest TPr concentrations for each storm event and for the overall study. Ranks were then compared and correlated to segmental precipitation values to determine if precipitation influenced TPr concentrations.

The frequency of specified TPr concentration values was determined to evaluate segments that contributed or absorbed the most and least throughout the study.

Results

Stream Segmentation GIS Data

The Northrup Creek Watershed was divided into eleven separate segments based of the eleven sampling points (Figure 3). Land use percentage, area, and parcels with septic tank were calculated throughout each of the eleven segments. Land use percentage, area, and parcels with septic tanks were calculated 90m from the creek. Inaddition, road kilometers were determined in each of the eleven segments. For this study, these calculated land use characteristics were broken up into 25 independent variables grouped into three categories: individual land uses, grouped land uses, and other land use factors. Value for each of the 25 independent land use variables are provided in Table 2. Figures illustrating the land use variable, soil hydrologic groups, and septic tank parcel locations for each segment are provided in Appendix 5-7. With the use of online aerial mapping (Google, 2010 and Bing, 2010), locations of community facilities that could influence TPr concentrations within each segment were identified (Table 3).

Storm Event Precipitation Data

Total storm precipitation at each of the four measurement stations was recorded and plotted on a density weighted map to determine a rough estimate of rainfall for the eleven segmental areas in six storm events (Table 4, Figure 4). Figures showing the density weighting of precipitation for each of the storm events are provided in Appendix 8. The July 13 storm event yielded the most precipitation with an average of 22.6 mm of rain among the eleven sampling locations. The June 22 storm event yielded the least amount of precipitation with an average of 4.3 mm of rain among the eleven sampling locations. The June 22, August 16, and September 13 storm events have a consistent amount of precipitation among the eleven sampling locations. Slightly more precipitation was recorded for the northern segments during the July 13 and August 5 storm events. Slightly more precipitation was recorded for the southern segments during the July 21 storm event.

Correlation of TPr Concentrations and Land Use Characteristics

Normality of Data

Normality of independent and dependent variables was determined for each storm event based on sampling and discharge results provided in Table 5. The normality and correlation tests used for the dependent variables TPr concentrations are shown in Table 6. Normal data is general preferred when conducting correlations tests and can be obtained by removing significant outlier from the data; however, removing several outliers from a small data set can derive biased results. Segments with TPr concentration values considered to be a significant outliner were removed to normalize the data. Storm events July 13 and August 5 had one segmental TPr concentration value considered outliners. These segment's TPr concentrations values were removed to create normalization of the data. Storm events June 22 and August 16 had more than one segmental TPr concentration values considered outliers. These segment's TPr concentration outliers were not removed, resulting in non-parametric data. Spearman's Correlation test was conducted on these the non-parametric storm event data.

Land use variables were further broken down into percentage and acreage to provide a total of 47 independent variables. These 47 independent variables were divided into three independent variable sections: independent land uses, land use groups, and other land uses. These 47 independent variables and their independent variable sections are shown in Table 6. The independent land uses section contains seven main land uses and their representative percentages and areas for the total of each land use section and areas 90 m from the creek. The independent land use section is comprised of 28 independent variables. The land use group section contains three land uses groups created by combining the seven main land use groups and their representative percentages and areas for the total of each land use section and areas 90m from the creek. The agricultural group is comprised of cropland and pasture land uses. The residential group is comprised of the barren/open/low and medium /high residential land uses. The vegetation group is comprised of forest, shrub/grasslands, and wetland land uses and is a representative of natural lands. The land use group section is comprised of twelve independent variables. The other land use group contains variables that could potentially have an effect on phosphorus concentrations in the creek. The other land use group is comprised of seven independent variables, including soil hydrologic groups and their representative areas and percentages, road miles, and septic tanks parcels and parcels 90m from the creek.

Individual Storm Events

June 22, 2010

Two land use variables were significantly correlated with TPr concentrations using the Spearman's Rho correlation test. Hydrologic Soil Groups A and B Area (Soil A/B Area) (ρ=0.035, n=11) and Residential Area (ρ=0.043, n=11) had a negative correlation with TPr concentrations.

Significant correlation data between TPr concentrations and land use variables for the June 22, 2010 storm event is shown in Table 7.

July 13, 2010

Six land use variables were significantly correlated with TPr concentrations using Pearson's correlation test. Forest 90m Area (ρ=0.004, n=9), Vegetation Group 90 m Area (ρ=0.006, n=9), Pasture 90 m Area (ρ=0.010, n=9), Shrub/Grassland 90 m Area (ρ=0.037, n=9), Agricultural 90 m Area (ρ=0.043, n=9), and Cropland Percentage (ρ=0.048, n=9) had a positive correlation with TPr concentration.

Five land use variables were significantly correlated with TPr concentrations using Spearman's Rho correlation test. Wetland Percentage (ρ=0.002, n=9), Residential Group Percentage (ρ=0.007, n=9), Residential Group 90 m Percentage (ρ=0.013, n=9), Barren/Open/Low Residential Percentage (ρ=0.025, n=9), and

Barren/Open/Low Residential 90 m Percentage (ρ=0.036, n=9) had a negative correlation with TPr concentrations. Significant correlation data between TPr concentrations and land use variables for the June 22, 2010 storm event is shown in Table 8.

July 21, 2010

Ten land use variables were significantly correlated with TPr concentrations using Pearson's correlation test. Vegetative Group 90 m Area (ρ=0.001, n=9), Forest 90 m Area (ρ=0.001, n=9), Pasture 90 m Area (ρ=0.009, n=9), Soil C/D Area (ρ=0.012, n=9), Wetlands 90 m Area (ρ=0.015, n=9), Forest Area (ρ=0.022, n=9), Vegetative Group Area (ρ=0.025, n=9), Pasture Area (ρ=0.034, n=9), Agricultural Group 90 m Area (ρ=0.036, n=9), and Agricultural Group Area (ρ=0.046, n=9) had a negative correlation with TPr concentrations.

Six land use variables were significantly correlated with TPr concentrations using the Spearman's Rho correlation test. Residential Group Percentage (ρ=0.002, n=9), Residential Group 90 m Percentage (ρ=0.013, n=9), Medium/High Residential 90 m Percentage (ρ=0.023, n=9), Medium/High Residential 90 m Area (ρ=0.039, n=9), Barren/Open/Low Residential 90 m Percentage (ρ=0.042, n=9), and Wetland Percentage (ρ=0.050, n=9), had a positive correlation with TPr concentrations.

Significant correlation data between TPr concentrations and land use variables for the July 21, 2010 storm event is shown in Table 9.

August 5, 2010

No variables had a significant correlation with TPr concentrations using either the Pearson's and Spearman's Rho correlations test.

August 16, 2010

No variables had a significant correlation with TPr concentrations using Spearman's Rho correlations test.

September 13, 2010

No variables had a significant correlation with TPr concentrations using Pearson's correlations test.

Two land use Variables were significantly correlated with TPr concentrations using the Spearman's Rho correlation test. Medium/High Residential 90 m Percentage (ρ=0.026, n=10) and Medium/High Residential 90 m Area (ρ=0.046, n=10) had a negative correlation with TPr concentrations.

Significant correlation data between TPr concentrations and land use for the September 13, 2010 storm event is shown in Table 10.

Average of the Storm Events

Four land use variables were significantly correlated with TPr concentrations using the Pearson's correlation test. Forest 90 m Area (ρ=0.005, n=10), Vegetative Group 90 m Area (ρ=0.017, n=10), Shrub/Grassland 90 m Area (ρ=0.032, n=10), and

Barren/Open/Low Residential Area (ρ=0.038, n=10) had a negative correlation with TPr concentrations.

No land use variables were significantly correlated with TPr concentrations using the Spearman's Rho correlation test.

Significant correlation data between TPr concentrations and land use variables for the average of the storm events is shown in Table 11.

<u>Modeling TPr Concentrations</u>

Individual Storm Events

June 22, 2010

No land use variables were entered in the stepwise regression for TPr concentrations.

July 13, 2010

Two land use variables were entered into the TPr concentration stepwise linear regression. Forest 90 m Area and Shrub/Grassland Percentage (ρ=0.002, F=22.892, df=8, Durbin-Watson=2.119) were entered to develop Equation 3 for modeling TPr concentrations for the July 13, 2013 storm event. Predicted values and residuals for the July 13, 2013 TPr model are provided in Table 12.

Equation 3: TPr = 196.370 + 4.951(Forest 90 m Area) - 22.892(Shrub/Grassland Percentage)

July 21, 2010

Two land use variables were entered into the TPr concentration stepwise linear regression. Vegetation Group 90 m Area and Shrub/Grassland Percentage ($\rho=0.001$, $F=31.819$, $df=8$, Durbin-Watson=2.014) were entered to develop Equation 5 for modeling TPr concentrations for the July 21, 2013 storm event. Predicted values and residuals for the July 21, 2013 TPr model are provided in Table 13.

Equation 4: TPr = 553.892 - 13.268(Vegetation Group 90 m Area) + 60.915(Shrub/Grassland Percentage)

August 5, 2010

No land use variables were entered in the stepwise regression for TPr concentrations.

August 16, 2010

No land use variables were entered in the stepwise regression for TPr concentrations.

September 13, 2010

No land use variables were entered in the stepwise regression for TPr concentrations.

Average of Storm Events

Two land use variables were entered into the TPr concentration stepwise linear regression. Barren/Open/Low Residential Area and Vegetation Group 90 m Area (ρ=0.000, F=27.901, df=9, Durbin-Watson=2.626) were entered to develop Equation 10 for modeling TPr concentrations for the average of the storm events. Predicted values and residuals for the average of the storm events TPr model are provided in Table 14.

Equation 5: TPr = 222.213 - 0.907(Barren/Open/Low Residential Area) - 0.757(Vegetation Group 90 m Area)

Segmental Rankings

Segment's ranking of TPr concentrations for each storm event and the average are provided in Table 15. Segments were arranged from largest TPr (value of one) to smallest (value of eleven).

TPr concentration rankings, with corresponding segments, from largest to smallest values are presented in Table 16. The highest value of TPr concentration calculated in this study was 5,025.34 μg/L in segment 3 during the July 16, 2010 storm event. The lowest value of TPr concentration was -953.98 in segment 6 during the August 5, 2010 storm event. The frequency of various TPr values by each segment is provided in Table 17.

Discussion

Correlation of TPr Concentrations and Land Use Characteristics

Individual Storm Events

The TPr concentration correlations between the 47 land use variables in this study seemed to vary between each of the six storm events. In some events, such as the July 21 event, results yield several strong correlations between TPr concentrations and land use variables. In other events, such as the June 22 event, there are not many correlations between TPr concentrations and land use variables. The August storm events did not find any correlation between TPr concentrations and land use variables.

Some land use variables have a strong positive correlation during one storm event and a strong negative correlation during another. An example of these can be seen in the Forest 90 m Area variable. The R^2 value correlating TPr concentrations and Forest 90 m Area during the July 13 event is 0.849 (ρ=0.004). The July 13 results suggest that forested land close to the creek increase the phosphorus concentrations in the runoff stormwater. However, the R^2 value for TPr concentrations and Forest 90 m Area during the July 21 event is -0.888 (ρ=0.001). The July 21 results suggest that forested land close to the creek decrease the phosphorus concentrations in the runoff stormwater. It is uncertain of what other factors may attribute to these inconsistencies in positive and negative correlations between TPr concentrations and these particular land use variables. The exact amount and location of precipitation within each segment during each of the storm events may have influenced this effect. Also, the land management of specific businesses in each of the segments, such as fertilizer application, erosion prevention, residential car washings, and other land use related management practices, may influence a particular individual storm events' phosphorus concentration and correlation results. In addition, TP concentration and discharge values at each sample location were not all collected at the exact same moment, but were collected over a period of an hour and a half due to the large size of the Northrup Creek Watershed. In some events, the northern most segments sample data was collected first. In other events, the southernmost segment sample data was collected first. These various timings of segment sample collection can produce errors in the data, as the first flush may have been collected for some segments, but not for others.

The independent land uses and land uses group independent variable sections representatives a majority of the Pearson's and Spearman's correlations for TPr concentrations. With only one total TPr concentrations, the variables within the other land use section seemed to not be a strong influence on TPr concentrations.

Several of the correlations during the individual storm events of this study were between TPr concentration and area-based land use variable. 22 area values and 22 percentage values were tested for correlation TPr concentrations for each storm event. For all six storm events, there are 19 correlations between area-based variables and TPr concentrations and 12 correlations between percentage-based variables and TPr concentrations. This suggests that quantitative land use area may be a more influential measurement of creek and runoff phosphorus concentration and land use correlations than land use percentage.

Several of the correlations during the individual storm events of this study were between TPr concentrations and land uses 90 m from the creek. 21 values were general land-based and 21 values were based 90 m from the creek where tested for correlation TPr concentrations for each storm event. For all six storm events, there are 18 correlations between 90 m-based land variables and TPr concentrations and 13 correlations between general-based land variables and TPr concentrations. This suggests that the land use types closest to the creek may have the most significant influence on the phosphorus concentration within runoff stormwater to the creek.

Average of the Storm Events

When averaging the normally distributed data for individual storm events, stronger patterns between land use and phosphorus concentration within runoff discharges can be determined. The four land use variables significantly correlated to TPr concentrations (Forest 90 m Area [R^2 = -0.806, ρ=0.005], Vegetative Group 90 m Area [R^2 = -0.729, ρ=0.017], Shrub/Grassland 90 m Area [R^2 = -0.677, ρ =0.032], and Barren/Open/Low Residential Area [R^2 = -0.661, ρ=0.038]) have a common theme of vegetative land. These strong, negatively correlated variables suggest that vegetative land, particularly vegetation closest to the stream, decreases the amount of total phosphorus in the runoff discharge. This suggests that the vegetation areas surrounding the creek, or buffer areas, may aid in removing or absorbing the TP before stormwater runoff enter the stream. In addition, the strong, negatively correlated Barren/Open/Low Residential Area variable suggest that a portion of residential lands may also influence the stormwater runoff by decreasing the amount of total phosphorus. The additional impervious area within the residential land use favors more runoff water, which in turn may dilute the amount of TP within the runoff and lower the TPr concentration.

There were no positive TPr concentration and land use correlations associated with the average of the storm events; therefore, there are no specific land use variables that are significantly shown to increase the TP to a creek through storm runoff.

Modeling TPr Concentrations

Stepwise linear regression modeling for TPr concentration values during individual storm events yields various predictive models and in some cases, none at all. In theory, independent variables with strong correlations to TPr should also appear within the model. This happens to be the case in the majority of the storm event models and also in the average of the storm event model. The variable with the highest Pearson's correlation value in the storm events was nearly always included within every storm event model for TPr concentrations.

Each individual storm event had its own unique model, indicating that each storm event's TPr concentrations are probably influenced by different land use variables at different times. Precipitation also has a strong influence on the difference in the individual storm event models. Precipitation rates and amounts are not uniform throughout all the land use segments and vary for each individual storm event; therefore, models for each storm event are expected to be slightly different. The evaluation of Doppler radar data corresponding to each storm event would have been a more relevant and accurate method in gathering average precipitation values throughout each segment.

When predicting TPr concentrations, four of the six storm events yield no model. The land use variables within the storm event models that do have models suggest that there is a vegetation influence. Residual values and the percentage of error for the individual TPr concentration predictive models both have a moderate range with some segment concentrations being predicted accurately and others inaccurately. When taking the average of the storm events, the Barren/Open/Low Residential Area variable along with the Vegetative Group 90 m Area variable were entered into the model.   Residuals values for the average TPr concentration predictive model ranges from 1.45 to 44.33 µ/L and error percentages between 0.7 and 120.9 percent. This suggests that close range buffer areas and barren/open areas with little residential impervious area have an influence on the amount of phosphorus entering the Northrup Creek. More storm events data should be evaluated and added to the data in this study to determine if the model for the average of the storm events remains the same or changes. If the models remain similar after additional data is added, then these area values could possibly be used for predicting the concentration of TPr added to Northrup Creek in each segment.

Further similar studies in Northrup Creek would have to be conducted each summer to compare the average TPr concentration models. If the average predictive models through each summer are relatively similar, then it can be concluded that specific land use variables may be used to effectively predict TPr concentrations for storm events in Northrup Creek.

Segmental Rankings

Segmental ranking for TPr concentrations were inconsistent between storm events. Some segments contained high TPr concentrations in one storm event and low TPr concentrations in other storm events. Several factors during each event could have led to the fluctuation of TPr concentrations, including soil moisture content, specific location and duration of rainfall within the segment, and turbid creek conditions exposing previous settled phosphorus. Based on the TPr values calculated in this study, Segment 3 ranks as the having the highest average TPr concentration and Segment 11 ranks as having the lowest average TPr concentration.

Using stream segmentation analysis, Segment 3 was identified as the greatest risk of contributing non-point source phosphorus through stormwater runoff. During the most significant storm event, July 13, the Segment 3 TPr concentrations values recorded 5025.34 μ/L. The immense amount of precipitation that fell on the watershed during this storm event may have allowed for additional physical influences to occur that may have not been present during the other less intense storm events. During less substantial storm events, the land adjacent to the creek may have more of an influence associated with the TPr concentrations than areas further within the watershed. In contrast, substantial storm events, as like the July 13 storm, can introduce runoff flow paths further away from the creek within the watershed. This can allow for a more representative collection of runoff entering the creek and influencing the TPr concentrations. In addition, the velocity of a creek can increase during a more significant storm event, creating more turbid conditions, allowing artifact particulate phosphorus settled within the sediment along the bottom of the creek to mix within the creek waters.

The largest land use within Segment 3 and 90 m from the creek in Segment 3 is forested/vegetative lands. Vegetative land typically is used to aid in absorbing phosphorus; however this may not be the case within Segment 3. A specific generalized land use, such as forested lands, may not be able to be linked directly to TPr concentration, but rather a more specific land use type could possibly account for the higher levels of phosphorus entering through runoff and groundwater infiltration. With the aid of online aerial land use maps, more specific businesses and land areas within Segment 3 could be identified, such as the Braemar Country Club and R.M. Landscape Company property. Braemar Country Club and associated golf course contains several greens and fairways that are adjacent to Northrup Creek and retaining basins/ponds that do not contain a buffer stripe or zone. The R.M Landscape property contains growing areas for various trees and plants and a pond without buffer stripes or zones that discharges into Northrup Creek. Both these businesses are likely to fertilize there properties at various times in order to provide customers with aesthetic view and products. It is possible that the high levels of TPr concentrations within Segment 3 can be directly related to the fertilization of these businesses and other similar lands that use fertilizer on their properties. Stormwater runoff from these businesses would pick up the access phosphorus in the form of fertilizer, and with the lack of a buffer zone, easily deposit the higher concentrated waters with higher concentrations of phosphorus into Northrup Creek.

Other specific land areas included in Segment 3 that may influence the high average TPr concentrations include an approximate 26 hectare developmentally disturbed and barren area and several large mansion-like residential properties including on property non-buffered ponds. Non-vegetation, loose soil from the barren land may be picked up during the heavy rain events and deposited into Northrup Creek tributaries located in Segment 3 creating a potential increase in TPr concentration entering in the creek.

Another influential specific land use is the old Spencerport STP, located within Segment 6 and upstream from Segment 3. Even though the STP was closed two years before this study was conducted, sewage and sludge remnants produced by processes of the STP may have an influence on the downstream quality of the creek. Previous studies have identified the STP as a major contributor of phosphorus to the Northrup Creek (Makarewicz, 1989 and Makarewicz and Lewis, 1990). It was also mentioned that the STP only performed secondary treatment of sewage, resulting in no removal of phosphorus from the sewage. Sediment adjacent and within the creek bottom downstream from the former STP may have high concentrations of phosphorus due to the settling of effluent particulates. During turbid conditions, this higher concentrated sediment can be kicked up, producing greater TP concentrations, within the creek. These higher values of TP concentrations would be unrelated to stormwater runoff, but would influence the calculated TPr concentration values downstream at Segments 3 and 6.

Segment 8 recorded the second highest average TPr concentrations. After all storm samples were collected, a portion of the Erie Canal was discovered to discharge into the Northrup Creek in Segment 8, slightly increasing the discharge of Northrup Creek in this area. The Erie Canal discharge may potentially carry higher TPr concentrations with it and would verify the high TPr concentrations in Segment 8; however TP concentration from the canal was not collected during storm events. Further research on the effect of Eric Canal TP concentrations entering Northrup Creek should be conducted to determine if the Eric Canal serves as a source of phosphorus to Northrup Creek.

Segment 11 is ranked as the having the lowest average TPr concentration. The majority of Segment 11 contains impervious, suburban residential areas and specific communal areas such as the Spencerport School complex and fields. These impervious areas potentially yield a higher stormwater runoff discharge that can possible help dilute TPr concentrations within Segment 11. In addition, the majority of the Spencerport MS4 lies within Segment 11. There are several MS4 outfalls discharging stormwater into Northrup Creek from residential homes and businesses within Segment 11. This collection of stormwater through the MS4 also potentially can dilute TPr concentrations.

Segment 6 is ranked as having the second lowest average TPr concentration; however, Segment 6 TPr concentration ranked the highest for the August 5th storm event with a value of 1651.75 µ/L. As in Segment 3, more specific land uses with an applied amount of phosphorus in the form of fertilizer during a specific time could account for this high TPr concentration value anomaly. Specific land uses in Segment 6 include two parks, Pineway Ponds and Rose Turner Parks, and a portion of residential land included in the Spencerport MS4.

Like Segment 3 and 6, other segments have a high TPr concentration value anomaly during one or more of the storm events. Segments 1, 2, 4, 8 and 10 contain at least one TPr concentration greater than 500 µ/L. Specific land uses, such as one or two particular farms, businesses, residences, and other land parcels would need to be further researched to determine if these anomalies are influenced by the application of specific high phosphorus containing products.

Segments 1, 2, 3, 6, and 11 calculated negative TPr concentration values during one or more storm events. These negative values were due to the upstream discharge values measuring greater than downstream discharge values. This indicated that phosphorus may have either been taken out of the system, or more likely, settled particulate phosphorus within the segment. A longer hydraulic residence time of the runoff within the segments due to physical obstructions, including retention ponds and low slope values may attribute to these negative values.

The possible slowing of creek flow within these segments can allow for the settlement of particulate phosphorus within the creek, creating lower downstream TP loading values and negative TPr concentration value.

Conclusion

The basis of this study was to evaluate the effect of general land use types between TPr concentrations contributing to the creek to aid in developing an efficient way to determine high and low risk areas of phosphorus contribution creek system. Identifying the significant land use variables and developing a predictive model as determined by GIS analysis, segmental stream analysis, stream flow data, and TP concentration grab samples would provide an alternative and more specific study into phosphorus contribution and reduction. Current TMDL studies use GIS based data and generic estimated loading values to prediction phosphorus loading. Under NYSDEC regulations, all industrial entities contributing stormwater discharge to an impaired waterbody with a TMDL or watershed improvement strategy are required to develop site specific models that monitor the contribution of the POC(s), such as phosphorus. Rather than identifying specific locations within a watershed that contribute non-point source of phosphorus, the TMDL phosphorus reduction method requires all entities inside the watershed contributing to the impaired waterbody to use and spend their own resources whether they increase phosphorus to the impaired waterbody or not. This study provides an evaluation to target specific areas or segments within a watershed that contribute to phosphorus using land use and stream specific concentration and flow data. This type of study will help entities that do not specifically contribute non-point source phosphorus save time and money and will direct the regulating agencies to specific entities that do contribute non-point sources of phosphorus to impaired waterbodies.

The measurement of land use variables, stream flow, and TP concentrations in Northrup Creek, a small watershed and creek system in Western New York discharging into a eutrophic pond adjacent to Lake Ontario, was analyzed using stream segment analysis in this study. Dividing the Northrup Creek watershed into multiple segments allowed for the identification of influential land use variables and targets specific segments that contribute non-point source phosphorus concentrations through storm runoff discharges. Highlighted statistical correlation and modeling results in the average of six storm events indicates that a combination decrease in forest area 90 m from the creek, vegetative group area 90 m from the creek, shrub/grasslands area 90 m from the creek, and barren/open/low residential area resulted in an increase of TPr concentrations in the creek system. Individual storm results yielded higher correlations between TPr concentrations and land use area and areas 90 m from the creek.

Previous studies comparing land use and phosphorous can support the validity to these average storm event correlation and modeling results. Results from this study and the Hubbard Brook Ecosystem Study indicated that decreasing vegetation within a watershed can increase the amount of phosphorus reaching the collecting stream. Forest and vegetative lands buffering adjacent to Northrup Creek was proven to be effective in the reduction of phosphorus in stormwater runoff. Similar results were discovered in the Kohler *et al.* and Moss *et al.* studies which revealed the effectiveness of buffer strips in reducing phosphorus in stromwater runoff alongside golf course creeks.

It was assumed that when using the average of the six storm events, a clear understanding of how the abovementioned land use variables statistically correlated with phosphorus runoff concentrations using previous studies to support the results; however, when comparing the individual storm events to each other, results were more vague, numerous, and complicated. Based on individual storm data analyses presented in this study, there is no clear way to pin point land use variables that increase or decrease TP concentrations. During the six storm events, several different land uses seems to correlate or influence the TP concentrations. Although when comparing each storm event, there was no consistency in these significant land uses variable and their predictive linear regression models. These results may be caused by several effects including the variation in runoff fluxes resulting in the dilution of phosphorus. Antecedent soil moisture conditions and timing of rainfall relative to the amount of phosphorus accumulation in the top of the soil zone have a large impact on the amount of dilution.

Average TPr concentration ranking were used to identify specific segments located within the Northrup Creek watershed that posed the highest and lowest risk of phosphorus contribution through stormwater runoff. Segments 3 and 8 showed the greatest risk of phosphorus contribution, while Segments 6 and 11 showed the least amount of risk. With the aid of aerial online mapping, specific facilities and areas within these high and low risk segments were identified, as shown in Table 3. The average TPr concentrations results from the six individual storm events, which varied in precipitation rates and duration. According to Table 4, five of the six storm events failed to produce more than 12.7 mm of precipitation. During these storm events, it is possible that only the runoff closely adjacent to the creek was represented. Depending on the soil moisture content and rainfall duration rates, runoff from land uses areas further within the segment, away from the creek, may have infiltrated into groundwater and not contributed to the creek, and therefore was not represented in the sample. In contrast, the July 13 storm event produced a substantial amount of precipitation across the Northrup Creek watershed and may have been the most representative of those land uses further away from the creek. More numerous and different runoff pathways throughout the segments could have been involved in discharging to the creek during the July 13 event that may have not been produced by the less significant storm events.

Contrasting previous studies aforementioned in the introduction of this study, an increase in residential lands in this study resulted in a decrease in phosphorus concentrations; however, these residential lands consisted of barren land, open fields and lawns, and low residential areas resulting in less between 20-49% imperviousness. Barrens lands, open lands, and low residential areas identified in the Northrup Creek watershed include park areas, cemeteries, golf courses, developmental lands, and suburban neighborhoods. Segments 3, 6, and 11 contained the greatest amount barren/open/low residential area. The majority of the barren/open/land use areas in low ranking segment 6 and 11 contained suburban neighborhoods. These results indicate that suburban neighborhoods can possible aid in reducing the concentration of phosphorus in stormwater runoff. The majority of barren/open/low residential area in the high ranked Segment 3 attributed to a golf course and barren land, which could be a source of the high TPr concentrations. The Winter and Dillion and Kunimatsu *et al.* studies discovering higher TP export and concentrations within creeks upstream from golf courses support these results.

The correlation, modeling, and segmental ranking results of this study were based on TPr concentrations, which was derived from upstream and downstream TP loading and discharge values. The validity of these TPr concentration values of each segment during individual storm event has been questioned throughout the study. Other physical processes, including the introduction of artifact phosphorus resulting from the Spencerport STP remnant, are believed to have influence the TPr concentrations, resulting in TPr concentrations unrepresentative of stormwater runoff during highly turbid events.

Further research regarding the correlation of vegetation and residential land uses on phosphorus concentrations in Northrup Creek is suggested to test the validity of the land use correlation results. Future studies suggested include the following:

a.) Monitoring the before and after TPr concentration during storm events of a sub-watershed where a vegetative buffer zone is introduced near the Northrup Creek or reforestation within the watershed is planned;

b.) Comparing Erie Canal TP values with Northrup Creek TP values before and after inflow to determine if source;

c.) Monitoring Northrup Creek TP concentrations and flow specifically within high risk area Segment 3 upstream and downstream of the Braemar Country Club during storm events to evaluate TPr Concentrations;

d.) Measuring TP in sediment and water within segments before and after storms to investigate the effect of phosphorus settling within Northrup creek.

Errors in the study may have resulted in inaccurate data. Several issues arose while collecting the TP concentration samples in the Northrup Creek watershed. The following are problems with this study that may have an influence on the data and results:

Collection of Samples

It would have been ideal to collect all water samples at the sample time directly just after the beginning of the storm event in order to collect the first flush. Unfortunately, the watershed is close to twenty miles long and took nearly two hours to collect all eleven samples. Therefore, some samples were taken directly after the start of the storm, while others were taken much later, creating discrepancies in the data. Having additional personnel collect the samples and record stage heights for each sampling location at one specific time is recommended.

Furthermore, a simple grab sample catch used in this study may have not been a good representation of the total phosphorus in the creek. Grab samples were taken within the middle cross section of the stream. A composite sample using grab samples taken from various locations between the creek bed and surface may have been more representative of the flow of phosphorus within the creek. A composite sample would take into consideration the heavier particulate phosphorus that may have been flowing deeper within the creek.

Land Use Inaccuracies

The GIS data used in the study, collected in 2006, was outdated. Several land use changes could have occurred between 2006 and 2010. These changes could have had a large impact on the TP concentrations collected. Comparing the outdated data with these effected TP concentrations mostly likely caused an error in the results. Unfortunately at the time, the 2006 was the most up-to-date land use data available. A 2010 land use data package is currently present for the Northrup Creek Watershed. A similar study is suggested to be performed using the updated land use data and then compared to this study, which uses the 2006 data.

Municipal Storm Sewers

The village of Spencerport contained a network of municipal storm sewers. Without obtaining drawings of these sewers, there was no way to determine the location of outfalls. Storm runoff collected in the sewers of one segment could have been drained through an outfall into another segment's portion of the creek. This displacement of collected stormwater could have increased or decreased the TP concentration in several segments. Obtaining the municipal stormwater sewer maps and planning the specific areas that discharge stormwater water to each outfall is recommended for future studies.

Discharge from the Erie Canal

Runoff stormwater in this study was not isolated to just the Northrup Creek; within segment eight, the Erie Canal discharges a portion of its flow to Northrup Creek. For example, Segment six, the downstream from segment eight, tended to have lower TP concentrations. This could have been a result of either absorption of phosphorus throughout segment six, or dilution of the TP concentration due to the Erie Canal discharge.

Although the outcome in the study was based only on a few storm events over one summer, viable land use and TPr concentration correlation results were identified along with suggested specific areas within the Northrup Creek Watershed that potentially have a high risk of contributing phosphorus through stormwater runoff. Correlation and ranking results, especially those using the average of the storm events, have shown to uphold the findings of a few previous studies. For instance, land with higher amounts of vegetation tends to release lower concentrations of phosphorus into the creek. This can also be said for lands that contain a vegetative buffer in close proximity to the creek. However, it was found that additional physical processes not analyzed in this study may have influenced the calculated TPr concentrations, suggesting unrepresentative values of runoff within the segments. Non-uniform storm rainfall duration and rates coupled with antecedent soil moisture content throughout the segments are very probable influences on the amount of phosphorus entering the creek at the various segments. A lower runoff residence time created by ponds and the low sloping areas is suggested to have aided in the settling of particulate phosphorus to the creek bed between segments, created negative TPr concentration values. Lastly, the introduction of artifact phosphorus back into the stream system, created by the former STP, through turbid creek conditions created a probable increase of TPr concentrations downstream.

With these additional physical processes occurring throughout the watershed system, it is inconclusive if the correlation, modeling and ranking results of this study are valid. True TPr concentrations values, which derived these results, are difficult to determine as the Northrup Creek Watershed system was found to be more complex than intended.

Literature Cited

American Public Health Association, American Water Works Association, and Water Environment Federation. 2005. Standard methods for the examination of water and wastewater. American Public Health Association, Washington D.C.

Bannerman, R. D. Owens, R. Dodds, and N.Horewer. 1993. Sources of pollutants in Wisconsin stormwater. Water Sci. Technol. 28:241-259

Barth, C. 1995. Nutrients: from the lawn to the stream. Watershed Protection Techniques 2(1): 239-246, Center for Watershed Protection, Ellicott City, Maryland, USA.

Bartsch, A.F. 1970. Accelerated eutrophication of lakes in the United States: Ecological response to human activities. Environ. Pollut. 1:133-140

Beaulac, M. N. and K.H. Reckhow. 1982. An examination of land use nutrient export relationships. J. Am. Water Resour. Assoc. 18:1013–1024

Barbosa, F.T., I. Bertol, R.V. Luciano, and A.P. Gonzalez. 2009. Phosphorus losses in water and sediments in runoff of the water erosion in oat and vetch crops seed in contour and downhill. Soil Tillage Res. 106:22-28

Bennett, E.M., S.R. Carpenter, N.F. Caraco. 2001. Human impact on erodible phosphorus and eutropication: A global perspective. BioScience. 51:227-234

Bennion, H., J. Hilton, M. Hughes, J. Clark, D. Hornby, I. Fozzard, G. Phillips, and C. Reynolds. 2005. The use of a GIS-based inventory to provide a national assessment of standing waters at risk from eutrophication in Great Britain. Sci. Total Environ. 344:259-273

Bormann, F.H., G.E. Likens, D.W. Fisher, and R.S. Pierce. 1968. Nutrient loss accelerated by clear-cutting of a forest ecosystem. Science. 159:882-884

Bullard, W.E. 1966. Effects of landuse on water resources. J. Water Pollut. Control Fed. 38:645-659

Burton, T.M. and J.E. Hook. 1979. Non-Point source pollution from abandoned agricultural land in the Great Lakes Basin. J. Great Lakes Res. 5:99-104

Caraco, N.F. 1995. Influence of human populations on P transfers to aquatic systems: a regional scale study using large rivers. Pages 235-244 *in* H. Tiessen, editor. Phosphorous in the global environment: transfers, cycles, and management. Wiley Press, Chinchester, United Kingdom.

Carpenter, S.R., Caraco, N.F., Correll, D.L, Howarth, R.W., Sharpley, A.N., and Smith V.H. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecol Appl 8:559-568.

Carpenter, S.R. 2005. Eutrophication of aquatic Ecosystems: Bistability and soil phosphorus. Proc Natl Acad Sci USA 102(29):10002-10005

Cochran, J., S. Clark, and M. Lalor. 2004. Effects of canopy cover on the volume of rain throughfall. Water Environment Federation Technical Exhibition and Conference, Session 81-90:550-556

Cornell University Geospatial Information Repository. 2011. Available at http://cugir.mannlib.cornell.edu.
Cook, G.W. and R.J.B. Williams. 1973. Significance of man-made sources of phosphorus: Fertilizers and farming. The phosphorous involved in agricultural systems and possibilities of its movement into natural waters. Water Res. 7:19-33
Dietz, M.E. and Clausen, J.C. 2008. Stormwater runoff and export changes with development in a traditional and low impact subdivision. J Environ Manage 87:560-566
Dillon, P.J. and W.B. Kirchner. 1975. The effects of geology and land use on the export of phosphorus from drainage basins. Water Res. 9:135-148
Dunne, E.J., J. Smith, D.B. Perkins, M.W. Clark, J.W. Jawitz, and K.R. Reddy. 2007. Phosphorus storage in historically isolated wetland ecosystems and surrounding pasture uplands. Ecol. Eng. 31:16-28
Ellison, M.E., Brett, M.T. 2006. Particulate phosphorus bioavailability as a function of stream flow and land cover. Water Research 40:1258-1268.
Evans, B.M., D.W. Lehning, K.J. Corradini, G.W. Petersen, E. Nizeyimana, J.M. Hamlett, P.D. Robillard, and R.L. Day. 2002. A comprehensive GIS-based modeling approach for predicting nutrient loads in watersheds. J. Spatial Hydrology, Vol. 2, No. 2
Gaynor, J.D. 1979. Phosphorus loadings associated with housing in a rural watershed. J. Great Lakes Res. 5:124-130
Gilbert, J.K. and J.C. Clausen. 2006. Stormwater runoff quality and quantity from asphalt, paver, and crushed stone driveways in Connecticut. Wat. Res. 40:826-832
Haith, D.A. and L.L. Shoemaker, 1987. Generalized watershed loading functions for stream flow nutrients. Water Resources Bulletin, 23(3), pp. 471-478.
Haygarth, P.M. 2005. Linking landscape sources of phosphorus and sediment to ecological impacts in surface waters. Sci Total Environ. 344:1-3
Hiscock, J.G., C.S. Thourot, and J. Zhang. 2003. Phosphorus budget—land use relationships for the northern Lake Okeechobee watershed, Florida. Ecol. Eng. 21:63-74
Hobbie, J.E. and G.E. Likens. 1973. Output of phosphorus, dissolved organic carbon and fine particulate carbon from Hubbard Brook Watersheds. Limnol. Oceanogr. 18:734-742
Hobbs F. and N. Stoops. 2002. Demographic trends in the 20th century. CENSR-4, United States Census Bureau, Washington D.C., USA
Jarvie, H.P., Neal, C. and Withers, P.J.A. 2006. Sewage-effluent phosphorus: a greater risk to river eutrophication than agricultural phosphorus? Sci Total Environ. 360:246–253

Jarvie, H.P., P.J.A Withers, M.J. Bowes, P. Wasiak, R.A. Hodgkinson, A. Bates, C. Stoate, M. Neal, H.D. Wickham, S.A. Harman, and L.K. Armstrong. 2010.

Streamwater nutrients and their sources across a gradient in rural-agricultural land use intensity. Agric. Ecosyst. Environ. 135(4):238-252
Kadlec, R.H. 2006. Free surface wetlands for phosphorus removal: The position of the Everglades Nutrient Removal project. Ecol. Eng. 24:361-379
Kato, T., Kuroda, H., and Nakasone, H. 2009. Runoff characteristics of nutrients from an agricultural watershed with intensive livestock production. J Hydrol. 368:79-87.
Knight, R.J., B. Gu, R.A. Clarke, and J.M. Newman. 2003. Long-term phosphorus removal in Florida aquatic systems dominated by submerged aquatic vegetation. Ecol. Eng. 20:45-63
Kohler, E.A., V.L. Poole, Z.J. Reicher, and R.F. Turco. 2004. Nutrient, metal, and pesticide removal during storm and nonstorm events by a constructed wetland on an urban golf course. Ecol. Eng. 25:285-298
Kovacs, A. and M. Honti. 2008. Estimation of diffuse phosphorus emissions at small catchment scale by GIS-based pollution potential analysis. Desalin. 226:72-80
Liu. Y. and J. Chen. 2008. Phosphorus Cycle. Pages 2715-2724 *in* S.E. Jorgensen, and B. Fath, editors. Encyclopedia of Ecology. Academic Press, Oxford, United Kingdom.
Kunimatsu, T., M. Sudo, and T. Kawachi. 1999. Loading rates of nutrients discharging from a gold course and a neighboring forested basin. Water Sci. Technol. 39:99-107
Makarewicz, J.C. 1989. Chemical analysis of water from Buttonwood, Larkin, Round Pond and Northrup Creeks, Lake Ontario Basin West, May 1987-May 1988. Prepared for the Monroe County Department of Health by the Department of Biological Sciences, SUNY, Brockport, NY, USA.
Makarewicz, J.C., T.W. Lewis, A. Brooks, and others. 1990. Chemical analysis and nutrient loading of Salmon Creek, Otis Creek, Black Creek, and the Spencerport Sewage Treatment Plant. Brockport, N.Y., SUNY Brockport. Available from Drake Library, SUNY Brockport. 120 p
Makarewicz, J.C. and T.W. Lewis. 1999. A technique for identifying pollution sources in a watershed: Stressed Stream Analysis revisited. The Information Exchange, the newsletter of the Finger Lakes - Lake Ontario Watershed Protection Alliance, 7(2), The Water Resource Board, Penn Yan, New York, USA.
Makarewicz, J.C. T.W. Lewis, and R.K. Williams. 1993. Nutrient loading of streams entering Sodus Bay and Port Bay, NY: A Summary of Port Bay and Sodus Bay Tributary Monitoring. Technical report to the Wayne County Soil and Water Conservation District, Sodus, NY, USA.
Makarewicz, J.C., T.W. Lewis, I. Bosch, M.R. Noll, N. Herendeen, R.D. Simon, J. Zollweg, and A. Vodacek. 2009. The impact of agricultural best management practices on downstream systems: Soil loss and nutrient chemistry and flux to Conesus Lake, New York, USA. *J.* Great Lakes Res. 35, 23–36

Miguntanna, N.P., A. Goonetilleke, P. Egodowatta, and S. Kokot. 2010. Understanding nutrient build-up on urban road surfaces. J. Environ. Sci. 22:806-812

Minnesota Pollution Control Agency. 2007. Phosphorus: Sources, Forms, Impact on Water Quality. Water Quality, Impaired Waters 3-12. St. Paul, Minnesota, USA.

Morris, W. and D. Traxler. 1996. Dakota County Subwatersheds: Residential Survey on Lawn Care and Water Quality. Decision Resources, Ltd, Dakota County, Minnesota, USA.

Moss, J.Q., G.E. Bell, M.A. Kizer, M.E. Payton, H, Zhang, and D.L. Martin. 2005. Reducing nutrient runoff from gold course fairways using grass buffers of multiple heights. Crop Sci. 46:72-80

National Land Cover Database. 2011. Available at http://www.mrlc.gov

New York State Comptroller. 2010. The Role of Agriculture in the New York State Economy. Report 21-2010, Office of the New York State Comptroller, New York City, New York, USA.

New York State Department of Environmental Conservation (NYSDEC). 2008. Part 703: Surface water groundwater quality standards groundwater effluent limitations. New York State Department of Environmental Conservation, Albany, New York. Available at http://www.dec.ny.gov/regs/4590.html.

New York State Department of Environmental Conservation (NYSDEC). 2011. New York State nutrient standards plan. New York State Department of Environmental Conservation, Albany, New York. Available at http://www.dec.ny.gov/docs/water_pdf/nutrientstds2011.pdf.

New York State GIS Clearinghouse. 2011. Available at http://gis.ny.gov

Noll, M.R. and E. Magee. 2006. Stressed Stream Analysis of the Larkin and Northrup Creek

"Northrup Creek Watershed." Map. Bing Maps. Bing, 18 Sept. 2010. Web. 18 Sept. 2010

"Northrup Creek Watershed." Map. Google Maps. Google, 18 Sept. 2010. Web. 18 Sept. 2010

Watersheds, Monroe County, New York. Prepared for The Stormwater Coalition of Monroe County by the Department of Biological Sciences, SUNY, Brockport, NY, USA.

Reddy, K.R., Y. Wang, W.F. DeBusk., M.M. Fisher, and S. Newman. 1998. Forms of soil phosphorus in selected hydrologic units of the Florida Everglades. Soil. Sci. Soc. Am. J. 62:1134-1147

Robbins, P. and T. Birkenholtz. 2003. Turfgrass Revolution: Measuring the Expansion of the American Lawn. Land Use Policy 20:181-194

Schindler, D.W. 1971. Carbon, Nitrogen and Phosphorus and the Eutrophication of Freshwater Lakes, Eur. J. Phycol. 7:321-329

Schindler, D.W. 1974. Eutrophication and recovery in experimental lakes: Implications for lake management. Science 194:897-899

Schueler, T. 1994. The Importance of Imperviousness. Watershed Protection Techniques. 1(3): 100-111, Center for Watershed Protection, Ellicott City, Maryland, USA.
Schueler, T. 1999b. On Watershed Education. Watershed Protection Techniques. 3(3): 680-686, Center for Watershed Protection, Ellicott City, Maryland, USA.
Schueler, T. 1999a. Understanding Watershed Behavior. Watershed Protection Techniques. 3(3): 671-678, Center for Watershed Protection, Ellicott City, Maryland, USA.
Sharpley, A.N., W. J. Gburek, G. Folmar, and H.B. Pionke. 1999. Sources of phosphorus exported from an agricultural watershed in Pennsylvania. Agric. Water Manage. 41:77-89
Simon, R.D. and J.C. Makarewicz. 2009. Storm water events in a small agricultural watershed: Characterization and evaluation of improvements in stream water microbiology following implementation of Best Management Practices. J. Great Lakes Res. 35:76-82
Smith, R.V. 1977. Domestic and agricultural contributions to the inputs of phosphorus and nitrogen to Lough Neagh. Water Res. 5:453-459
Smith, A. J., Bode, R. W., and Kleppel, G. S. (2007). A nutrient biotic index (NBI) for use with benthic macroinvertebrate communities. Ecological Indicators, 7(2), 371-386
Smith, D.J. and H. Shilley. 2009. Residential car washwater monitoring study. Public Works and Surface Water Management, City of Federal Way, Washington, USA.
Sparks, D.L. 2003. Environmental soil chemistry. Second Edition. Academic Press, San Diego, California, USA.
Soranno, P.A., S.L. Hubler, and S.R. Carpenter. 1996. Phosphorus loads to surface waters: A simple model to account for spatial of land use. Ecol. Appl. 6:865-878.
Swann, C. 1999. A Survey of Residential Nutrient Behaviors in the Chesapeake Bay. Widener Burrows, Inc., Chesapeake Research Consortium. Center for Watershed Protection. Ellicott City, MD.
Tonderski, K.S., B. Arheimer, and C.B. Pers. 2005. Modeling the impact of potential wetlands on phosphorus retention in a Swedish catchment. J. Hum. Environ. 27:361-379
Turtola, E. and A. Paajanen. 1995. Influence of improved subsurface drainage on phosphorus losses and nitrogen leaching from a heavy clay soil. Agric. Water Manage. 28:295-310
U.S. Department of Agriculture, Natural Resources Conservation Service. National Soil Survey Handbook, title 430-VI

Vadas, P.A., L.B. Owens, and A.N. Sharpley. 2008. An empirical model for dissolved phosphorus in runoff from surface-applied fertilizers, Agr Ecosyst Environ. 127:59-65

Wickham, J.D. and T.G. Wade. 2002. Watershed level risk assessment of nitrogen and phosphorus export. Comput. Electron. Agric. 37:15-24

Winter J.G. and P.J. Dillon. 2006. Export of nutrients from golf courses on the Precambrian Shield. Environ. Pollut. 141:550-554

Withers, P.J.A., H.P. Jarvie, and C. Stoate. 2011. Quanitifying the impact of septic tank systems on eutrophication risk in rural headwaters. Environ. Int. 37:644-653

Withers, P.J.A., H.P. Jarvie, R.A. Hodgkinson, E.J. Palmer-Felgate, A. Bates, M. Neal, R. Howells, C.M. Withers, and H.D. Wickham. 2009. Characterization of Phosphorus Sources in Rural Watersheds. J. Environ. Qual. 38:1998–2011.

Zhang, T., Soranno, P.A., Cheruvelil, K.S., Kramer, D.B., Bremigan, M.T., and Ligmann-Zielinska, A. 2012. Evaluating the effects of upstream lakes and wetlands on lake phosphorus concentrations using a spatially-explicit model. Landscape Ecol. 27: 1015-1030.

Zobrist, J., S.R. Muller, A. Ammann, T.D. Bucheli, V. Mottier, M. Ochss, R. Schoenenberger, J.Eugster, and M. Boller. 2000 Quality of roof runoff for groundwater infiltration. Wat. Res. 34:1455-1462

Tables

Table 1: North American annual average phosphorus export (kg/ha/yr) (Beaulac and Reckhow, 1982 and Young, 1996)

General Land Use Type	Range (kg/Ha/yr)	Median (kg/Ha/yr)
Urban	0.7-2.8	1.2
Pasture	0.3-2.8	0.9
Mixed Agriculture	0.5-1.5	1.0
Row Crops	1.0-5.3	2.3
Non-row Crops	1.0-1.6	0.8
Forest	0.1-0.4	0.3

Table 2: Segmental land use variable calculations

	Segment 1			Segment 2			Segment 3		
Total 900 m^2 Pixels	6998			7460			8534		
Total 90 m 900 m^2 Pixels	1328			980			841		
Total Land Area (Ha)	630.7			670.3			768.1		
Total Land Area 90 m (Ha)	155.2			102.1			94.3		
Land Use Type	Pixels	%	Ha	Pixels	%	Ha	Pixels	%	Ha
Cropland	2346	33.5	211.4	2908	39.0	261.3	693	8.1	62.4
Pasture	2171	31.0	195.7	2930	39.3	263.3	1603	18.8	144.3
Open Residential	323	4.6	29.1	463	6.2	41.6	1036	12.1	93.2
Low Residential	140	2.0	12.6	122	1.6	11.0	220	2.6	19.8
Medium Residential	76	1.1	6.8	3	0.0	0.3	90	1.1	8.1
High Residential	12	0.2	1.1	1	0.0	0.1	26	0.3	2.3
Barren Land	24	0.3	2.2	0	0.0	0.0	193	2.3	17.4
Forest	1715	24.5	154.6	842	11.3	75.7	4182	49.0	376.4
Shrubs/Grassland	50	0.7	4.5	73	1.0	6.6	307	3.6	27.6
Wetland	141	2.0	12.7	118	1.6	10.6	184	2.2	16.6
Cropland 90 m	113	8.5	13.2	247	25.2	25.7	92	10.9	10.3
Pasture 90 m	494	37.2	57.7	370	37.8	38.5	168	20.0	18.8
Open Residential 90 m	64	4.8	7.5	7	0.7	0.7	196	23.3	22.0
Low Residential 90 m	6	0.5	0.7	17	1.7	1.8	0	0.0	0.0
Medium Residential 90 m	5	0.4	0.6	0	0.0	0.0	0	0.0	0.0
High Residential 90 m	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
Forest 90 m	526	39.6	61.5	213	21.7	22.2	352	41.9	39.5
Shrubs/Grassland 90 m	26	2.0	3.0	23	2.3	2.4	5	0.6	0.6
Wetland 90 m	94	7.1	11.0	103	15.4	15.7	28	3.3	3.1
Agricultural Group	4517	64.5	407.1	5838	78.3	524.6	2296	26.9	206.7
Residential Group	575	8.2	51.8	589	7.9	52.9	1565	18.3	140.9
Vegetation Group	1765	25.2	159.1	915	12.3	82.2	4489	52.6	404.0
Agricultural Group 90 m	607	45.7	70.9	617	63.0	64.3	260	30.9	29.2
Residential Group 90 m	11	0.8	1.3	17	1.7	1.8	0	0.0	0.0
Vegetation Group 90 m	646	48.6	75.5	339	34.6	35.3	385	45.8	43.2
Hydrologic Soil Group A		0.0	0.0		1.1	7.5		2.7	20.9
Hydrologic Soil Group B		28.2	178.1		33.8	226.3		39.4	302.4
Hydrologic Soil Group C		68.3	430.6		59.9	401.3		35.4	271.8
Hydrologic Soil Group D		3.4	21.5		5.1	34.5		22.1	169.6
Road Miles		9.5			10.0			12.7	
Septic Tank Parcels		79			201			338	
Septic Tank Parcels 90 m		26			42			117	

Table 2 cont.

	Segment 4			Segment 5			Segment 6		
Total 900 m^2 Pixels	7789			6124			7029		
Total 90 m 900 m^2 Pixels	1140			793			1525		
Total Land Area (Ha)	702.2			551.0			633.5		
Total Land Area 90 m (Ha)	113.2			79.7			169.7		
Land Use Type	Pixels	%	Ha	Pixels	%	Ha	Pixels	%	Ha
Cropland	1600	20.5	144.2	873	14.3	78.5	550	7.8	49.6
Pasture	2197	28.2	198.1	1383	22.6	124.4	1648	23.4	148.5
Open Residential	317	4.1	28.6	526	8.6	47.3	624	8.9	56.2
Low Residential	96	1.2	8.7	62	1.0	5.6	599	8.5	54.0
Medium Residential	77	1.0	6.9	67	1.1	6.0	66	0.9	5.9
High Residential	20	0.3	1.8	0	0.0	0.0	11	0.2	1.0
Barren Land	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
Forest	2889	37.1	260.5	2728	44.5	245.4	2638	37.5	237.8
Shrubs/Grassland	150	1.9	13.5	235	3.8	21.1	386	5.5	34.8
Wetland	443	5.7	39.9	250	4.1	22.5	466	6.6	42.0
Cropland 90 m	144	12.6	14.3	19	2.4	1.9	75	4.9	8.3
Pasture 90 m	344	30.2	34.2	179	22.6	18.0	305	20.0	33.9
Open Residential 90 m	49	4.3	4.9	20	2.5	2.0	103	6.8	11.5
Low Residential 90 m	12	1.1	1.2	5	0.6	0.5	72	4.7	8.0
Medium Residential 90 m	0	0.0	0.0	0	0.0	0.0	2	0.1	0.2
High Residential 90 m	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
Forest 90 m	428	37.5	42.5	410	51.7	41.2	856	56.1	95.3
Shrubs/Grassland 90 m	10	0.9	1.0	39	4.9	3.9	42	2.8	4.7
Wetland 90 m	153	13.4	15.2	121	15.3	12.2	70	4.6	7.8
Agricultural Group	3797	48.7	342.3	2256	36.8	203.0	2198	31.3	198.1
Residential Group	510	6.5	46.0	655	10.7	58.9	1300	18.5	117.2
Vegetation Group	3039	39.0	274.0	2963	48.4	266.6	3024	43.0	272.5
Agricultural Group 90 m	488	42.8	48.5	198	25.0	19.9	380	24.9	42.3
Residential Group 90 m	12	1.1	1.2	5	0.6	0.5	74	4.9	8.2
Vegetation Group 90 m	591	51.8	58.7	570	71.9	57.3	968	63.5	107.7
Hydrologic Soil Group A		3.5	24.8		8.5	46.8		10.0	63.5
Hydrologic Soil Group B		24.9	175.2		39.2	215.8		52.8	334.2
Hydrologic Soil Group C		50.8	356.6		33.2	182.8		27.2	172.6
Hydrologic Soil Group D		20.6	144.3		19.2	105.5		6.4	40.5
Road Miles		6.5			7.7			15.2	
Septic Tank Parcels		142			208			304	
Septic Tank Parcels 90 m		62			50			156	

Table 2 cont.

	Segment 7			Segment 8			Segment 9		
Total 900 m^2 Pixels	2515			470			3979		
Total 90 m 900 m^2 Pixels	229			172			445		
Total Land Area (Ha)	226.3			37.5			358.2		
Total Land Area 90 m (Ha)	21.7			22.2			60.2		
Land Use Type	Pixels	%	Ha	Pixels	%	Ha	Pixels	%	Ha
Cropland	309	12.3	27.8	0	0.0	0.0	804	20.2	72.4
Pasture	572	22.7	51.5	14	3.0	1.1	1101	27.7	99.1
Open Residential	318	12.6	28.6	74	15.7	5.9	563	14.1	50.7
Low Residential	40	1.6	3.6	103	21.9	8.2	194	4.9	17.5
Medium Residential	1	0.0	0.1	27	5.7	2.2	99	2.5	8.9
High Residential	0	0.0	0.0	12	2.6	1.0	7	0.2	0.6
Barren Land	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
Forest	1075	42.7	96.7	99	21.1	7.9	852	21.4	76.7
Shrubs/Grassland	62	2.5	5.6	38	8.1	3.0	10	0.3	0.9
Wetland	138	5.5	12.4	94	20.0	7.5	349	8.8	31.4
Cropland 90 m	22	9.6	2.1	0	0.0	0.0	93	20.9	12.6
Pasture 90 m	33	14.4	3.1	3	1.7	0.4	99	22.2	13.4
Open Residential 90 m	7	3.1	0.7	31	18.0	4.0	118	26.5	16.0
Low Residential 90 m	14	6.1	1.3	41	23.8	5.3	19	4.3	2.6
Medium Residential 90 m	0	0.0	0.0	9	5.2	1.2	9	2.0	1.2
High Residential 90 m	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
Forest 90 m	145	63.3	13.7	48	27.9	6.2	83	18.7	11.2
Shrubs/Grassland 90 m	3	1.3	0.3	0	0.0	0.0	0	0.0	0.0
Wetland 90 m	5	2.2	0.5	32	18.6	4.1	24	5.4	3.2
Agricultural Group	881	35.0	79.3	14	3.0	1.1	1905	47.9	171.5
Residential Group	359	14.3	32.3	216	46.0	17.2	863	21.7	77.7
Vegetation Group	1137	45.2	102.3	137	29.1	10.9	862	21.7	77.6
Agricultural Group 90 m	55	24.0	5.2	3	1.7	0.4	192	43.1	26.0
Residential Group 90 m	14	6.1	1.3	50	29.1	6.5	28	6.3	3.8
Vegetation Group 90 m	153	66.8	14.5	80	46.5	10.3	107	24.0	14.5
Hydrologic Soil Group A		19.5	44.2		1.0	0.3		5.1	18.1
Hydrologic Soil Group B		53.3	120.6		39.4	11.6		27.4	98.2
Hydrologic Soil Group C		21.4	48.5		12.7	3.8		55.7	199.5
Hydrologic Soil Group D		5.5	12.4		67.3	19.9		10.0	35.7
Road Miles		5.2			1.7			21.2	
Septic Tank Parcels		86			0			80	
Septic Tank Parcels 90 m		29			0			37	

Table 2 cont.

	Segment 10			Segment 11		
Total 900 m^2 Pixels	6230			3057		
Total 90 m 900 m^2 Pixels	277			585		
Total Land Area (Ha)	561.1			313.4		
Total Land Area 90 m (Ha)	47.2			102.7		
Land Use Type	Pixels	%	Ha	Pixels	%	Ha
Cropland	1408	22.6	126.8	228	7.5	23.4
Pasture	1508	24.2	135.8	176	5.8	18.0
Open Residential	422	6.8	38.0	1001	32.7	102.6
Low Residential	245	3.9	22.1	801	26.2	82.1
Medium Residential	222	3.6	20.0	244	8.0	25.0
High Residential	15	0.2	1.4	64	2.1	6.6
Barren Land	7	0.1	0.6	44	1.4	4.5
Forest	1005	16.1	90.5	260	8.5	26.7
Shrubs/Grassland	83	1.3	7.5	100	3.3	10.3
Wetland	1314	21.1	118.3	97	3.2	9.9
Cropland 90 m	116	41.9	19.8	0	0.0	0.0
Pasture 90 m	89	32.1	15.2	21	3.6	3.7
Open Residential 90 m	8	2.9	1.4	205	35.0	36.0
Low Residential 90 m	14	5.1	2.4	114	19.5	20.0
Medium Residential 90 m	38	13.7	6.5	22	3.8	3.9
High Residential 90 m	0	0.0	0.0	30	5.1	5.3
Forest 90 m	0	0.0	0.0	135	23.1	23.7
Shrubs/Grassland 90 m	2	0.7	0.3	16	2.7	2.8
Wetland 90 m	10	3.6	1.7	42	7.2	7.4
Agricultural Group	2916	46.8	262.6	404	13.2	41.4
Residential Group	911	14.6	82.0	2154	70.5	220.8
Vegetation Group	1088	17.5	98.0	360	11.8	36.9
Agricultural Group 90 m	205	74.0	34.9	21	3.6	3.7
Residential Group 90 m	52	18.8	8.9	166	28.4	29.1
Vegetation Group 90 m	12	4.3	2.0	193	33.0	33.9
Hydrologic Soil Group A		3.9	22.1		17.1	47.2
Hydrologic Soil Group B		39.5	221.6		60.2	165.9
Hydrologic Soil Group C		37.2	208.9		15.1	41.8
Hydrologic Soil Group D		12.2	68.7		4.4	12.1
Road Miles		14.1			11.4	
Septic Tank Parcels		213			29	
Septic Tank Parcels 90 m		78			3	

Table 3**:** Segmental communal facilities and development.

Segment	Constructed Communal Feature	Year(s) Developed/Used	Area (Ha)
1	YMCA's Camp Northpoint	2006	19.4
	North Greece Fire Department Station 1	2004-2005	2.0
	North Greece First Bible Baptist Church	2004-2007	39.7
	Bridge over Northrup Creek (200 m from SP1)	2010	< 1.0
2	Parma, NY Union Cemetery	1853-Present	4.5
	Parma Town Hall and Park	1969-Present	86.0
3	Braemar Country Club (Golfing Area)	1927-Present	56.7
	Victory Community Church	Unknown-Present	1.6
	Greece Little League Complex	1997-Present	15.0
	Lakeshore Community Church	2003-2004	6.5
	Developmentally Disturbed Barren Area	Unknown-Present	26.0
	R.M. Landscape, Inc.	~1990-Present	18.0
	Large Residences with Aesthetic Ponds Discharging to Northrup Creek Tributaries	Unknown-Present	~7.5
4	Parma Corners Cemetery	Pre-1820 - Present	1.9
5	Parma Town Hall and Park	1969-Present	30.0
	Slavic Pentecostal Church	2001	40.0
	Spencerport Bible Church Addition	2004	< 1.0
6	Former Spencerport Sewer Treatment Plant	Closed in 2008	< 1.0
	Taylor Elementary School	Unknown-Present	9.0
	Pineway Ponds Park	Unknown-Present	29.4
	Rose Turner Park	Unknown-Present	6.5
	Spencerport, NY MS4	Current	N/A
7	Cobble Creek Farm	~1933-Present	85.0
	Spencerport, NY MS4	Current	N/A
8	Erie Canal Discharge Entrance	Current	< 1.0
	WEMOCO Career and Technical Education Center	Unknown-Present	8.0
9	Spencerport Airpark	2010-Present	6.1
	Colby Homestead Farms (dairy farm: ~250 cattle)	1802-Present	78.1
10	Town of Ogden, NY Highway Department Building	Unknown-Present	20.0
	Dry Bean Farm	Unknown-Present	15.0
11	Spencerport High/Middle/Elementary School	Unknown-Present	74.0
	Village of Spencerport Center	1867-Present	0.6
	Fairfield Cemetery	Pre-1860 - Present	3.0
	Spencerport, NY MS4	Current	N/A

Table 4: Storm event density weighted precipitation values and averages. Values were calculated at each segment's sampling point.

	Segment Precipitation (mm)											
Date	1	2	3	4	5	6	7	8	9	10	11	Avg.
6/22/2010	3.2	2.9	4.7	3.6	4.6	5.4	4.9	5.4	4.8	6.7	5.3	4.7
7/13/2010	28.6	32.3	20.7	26.0	21.6	18.8	20.4	18.5	18.8	15.0	18.4	21.7
7/21/2010	2.9	2.9	6.1	4.6	6.5	7.9	7.2	8.3	7.9	10.7	8.4	6.6
8/5/2010	6.2	7.1	5.1	6.4	5.4	4.6	5.0	4.5	4.6	3.7	4.5	5.2
8/16/2010	6.3	7.0	6.3	6.9	6.5	6.4	6.5	6.5	6.6	6.4	6.6	6.5
9/13/2010	8.8	7.0	8.5	7.1	7.9	8.1	7.9	8.0	7.6	7.9	7.8	7.9
Average	9.3	9.9	8.6	9.1	8.7	8.5	8.6	8.5	8.4	8.4	8.5	8.8

Table 5: Normality of the dependent variables TPr and the correlation tests used. Segments with values that were considered outliers were removed to normalize the data.

Variable	**Storm Event**	**Normality**	**Correlation Test Used**	**Segments Removed**
Dependent Variable TPr	6/22/2010	Non-Parametric	Spearman's	
	7/13/2010	Parametric	Pearson's	3
	7/21/2010	Parametric	Pearson's	
	8/5/2010	Parametric	Pearson's	6
	8/16/2010	Non-Parametric	Spearman's	
	9/13/2010	Parametric	Pearson's	
	Average	Parametric	Pearson's	3

Table 6: Land use variables, normality of the land use variables, and type of correlation test performed using the land uses variables.

Independent Variables		Normality	Correlation Test Used
Individual Land Uses	Cropland Percentage	Parametric	Pearson's
	Cropland Acreage	Parametric	Pearson's
	Pasture Percentage	Parametric	Pearson's
	Pasture Acreage	Parametric	Pearson's
	Barren/Open/Low Residential Percentage	Non-Parametric	Spearman's
	Barren/Open/Low Residential Acreage	Parametric	Pearson's
	Medium/High Residential Percentage	Non-Parametric	Spearman's
	Medium/High Residential Acreage	Non-Parametric	Spearman's
	Forest Percentage	Parametric	Pearson's
	Forest Acreage	Parametric	Pearson's
	Shrubs/Grassland Percentage	Parametric	Pearson's
	Shrubs/Grassland Acreage	Non-Parametric	Spearman's
	Wetland Percentage	Non-Parametric	Spearman's
	Wetland Acreage	Non-Parametric	Spearman's
	Cropland 90 m Percentage	Parametric	Pearson's
	Cropland 90 m Acreage	Parametric	Pearson's
	Pasture 90 m Percentage	Parametric	Pearson's
	Pasture 90 m Acreage	Parametric	Pearson's
	Barren/Open/Low Residential 90 m Percentage	Non-Parametric	Spearman's
	Barren/Open/Low Residential 90 m Acreage	Non-Parametric	Spearman's
	Medium/High Residential 90 m Percentage	Non-Parametric	Spearman's
	Medium/High Residential 90 m Acreage	Non-Parametric	Spearman's
	Forest 90 m Percentage	Parametric	Pearson's
	Forest 90 m Acreage	Parametric	Pearson's
	Shrubs/Grassland 90 m Percentage	Parametric	Pearson's
	Shrubs/Grassland 90 m Acreage	Parametric	Pearson's
	Wetland 90 m Percentage	Non-Parametric	Spearman's
	Wetland 90 m Acreage	Parametric*	Pearson's
Land Use Groups	Agricultural Group Percentage	Parametric	Pearson's
	Agricultural Group Acreage	Parametric	Pearson's
	Residential Group Percentage	Non-Parametric	Spearman's
	Residential Group Acreage	Parametric	Pearson's
	Vegetation Group Percentage	Parametric	Pearson's
	Vegetation Group Acreage	Parametric	Pearson's
	Agricultural Group 90 m Percentage	Parametric	Pearson's
	Agricultural Group 90 m Acreage	Parametric	Pearson's
	Residential Group 90 m Percentage	Non-Parametric	Spearman's
	Residential Group 90 m Acreage	Parametric	Pearson's
	Vegetation Group 90 m Percentage	Parametric	Pearson's
	Vegetation Group 90 m Acreage	Parametric	Pearson's
Other Land Use Factors	Hydrologic Soil Group A/B Percentage	Parametric	Pearson's
	Hydrologic Soil Group A/B Acreage	Parametric	Pearson's
	Hydrologic Soil Group C/D Percentage	Parametric	Pearson's
	Hydrologic Soil Group C/D Acreage	Parametric	Pearson's
	Road Miles	Parametric	Pearson's
	Septic Tank Parcels	Parametric	Pearson's
	Septic Tank Parcels 90 m	Parametric	Pearson's

* Value parametric when segment when segment 10 removed.

Table 7: June 22, 2010 storm event TPr concentration correlations variables and values.

.Variable	Correlation Test	R^2 value	ρ value	n value
Soil A/B Area	Spearman's Rho	-0.636	0.035	11
Residential Group Area	Spearman's Rho	-0.618	0.043	11

Table 8: July 13, 2010 storm event TPr concentration correlations variables and values.

Variable	Correlation Test	R^2 value	ρ value	n value
Forest 90 m Area	Pearson's	0.849	0.004	9
Vegetation Group 90 m Area	Pearson's	0.827	0.006	9
Pasture 90 m Area	Pearson's	0.796	0.010	9
Shrub/Grasslands 90 m Area	Pearson's	0.696	0.037	9
Agricultural Group 90 m Area	Pearson's	0.682	0.043	9
Cropland Percentage	Pearson's	0.671	0.048	9
Residential Group Percentage	Spearman's Rho	-0.817	0.007	9
Wetland Percentage	Spearman's Rho	-0.850	0.004	9
Residential Group 90 m Percentage	Spearman's Rho	-0.783	0.013	9
Barren/Open/Low Residential Percentage	Spearman's Rho	-0.733	0.025	9
Barren/Open/Low Residential 90 m Percentage	Spearman's Rho	-0.700	0.036	9

Table 9: July 21, 2010 storm event TP and TPr concentration correlations variables and values.

Variable	Correlation Test	R^2 value	ρ value	n value
Vegetative Group 90 m Area	Pearson's	-0.893	0.001	8
Forest 90 m Area	Pearson's	-0.888	0.001	8
Pasture 90 m Area	Pearson's	-0.803	0.009	8
Soil C/D Area	Pearson's	-0.783	0.012	8
Wetland 90 m Area	Pearson's	-0.769	0.015	8
Forest Area	Pearson's	-0.742	0.022	8
Vegetative Group Area	Pearson's	-0.731	0.025	8
Pasture Area	Pearson's	-0.706	0.034	8
Agricultural Group 90 m Area	Pearson's	-0.699	0.036	8
Agricultural Group Area	Pearson's	-0.676	0.046	8
Residential Group Percentage	Spearman’s Rho	0.867	0.002	8
Residential Group 90 m Percentage	Spearman’s Rho	0.783	0.013	8
Medium/High Residential 90 m Percentage	Spearman's Rho	0.740	0.023	8
Medium/High Residential 90 m Area	Spearman's Rho	0.691	0.039	8
Barren/Open/Low Residential 90 m Percentage	Spearman's Rho	0.683	0.042	8
Wetland Percentage	Spearman's Rho	0.667	0.050	8

Table 10: September 13, 2010 storm event TP and TPr concentration correlations variables and values.

Variable	Correlation Test	R^2 value	ρ value	n value
Medium/High Residential 90 m Percentage	Spearman's Rho	-0.694	0.026	10
Medium/High Residential 90 m Area	Spearman's Rho	-0.640	0.046	10

Table 11: Average of the storm events TP and TPr concentration correlations variables and values.

Variable	Correlation Test	R^2 value	ρ value	n value
Forest 90 m Area	Pearson’s	-0.806	0.005	10
Vegetative Group 90 m Area	Pearson’s	-0.729	0.017	10
Shrub/Grassland 90 m Area	Pearson’s	-0.677	0.032	10
Barren/Open/Low Residential Area	Pearson’s	-0.661	0.038	10

Table 12: TPr stepwise model data for the July 13, 2013 Storm Event.

Segment	Forest 90 m Area	Shrub/ Grassland Percentage	Calculated TPr Concentration	Predicted TPr Concentration	Residual	Percent Error
1	61.5	0.7	501.97	484.04	17.93	3.6
2	22.2	1.0	337.17	283.39	53.78	15.9
3	39.5	3.6	N/A*	N/A	N/A	N/A
4	42.5	1.9	300.40	361.83	61.43	20.4
5	41.2	3.8	294.75	310.80	16.05	5.4
6	95.3	5.5	N/A	N/A	N/A	N/A
7	13.7	2.5	263.58	206.84	56.74	21.5
8	6.2	8.1	22.36	38.29	15.93	71.2
9	11.2	0.3	186.95	246.09	59.14	31.6
10	0.0	1.3	146.42	165.27	18.85	12.9
11	23.7	3.3	279.25	237.34	41.91	15.0

N/A data

**Segment 3 TPr value was an outlier and not entered into the model.*

Table 13: TPr stepwise model data for the July 21, 2013 Storm Event.

Segment	Vegetation Group 90 m Area	Shrub/ Grassland Percentage	Calculated TPr Concentration	Predicted TPr Concentration	Residual	Percent Error
1	75.5	0.7	-279.74	-404.27	124.53	44.5
2	35.3	1.0	N/A	N/A	N/A	N/A
3	43.2	3.6	N/A	N/A	N/A	N/A
4	58.7	1.9	-319.41	-107.43	211.98	66.4
5	57.3	3.8	103.81	27.55	76.26	73.5
6	107.7	5.5	N/A	N/A	N/A	N/A
7	14.5	2.5	347.34	511.70	164.36	47.3
8	10.3	8.1	926.89	909.40	17.49	1.9
9	14.5	0.3	443.05	377.15	65.90	14.9
10	2.0	1.3	711.67	607.92	103.75	14.6
11	33.9	3.3	371.94	303.61	68.33	18.4

Table 14: TPr stepwise model data for the average of the storm events.

Segment	Barren/Open/ Low Residential Area	Vegetation Group 90 m Area	Calculated TPr Concentration	Predicted TPr Concentration	Residual	Percent Error
1	43.9	75.5	131.06	125.24	5.82	4.4
2	17.0	35.3	188.22	180.06	8.16	4.3
3	130.4	43.2	N/A*	N/A	N/A	N/A
4	37.2	58.7	99.72	144.05	44.33	44.5
5	52.9	57.3	138.19	130.87	7.32	5.3
6	111.2	107.7	59.31	39.81	19.50	32.9
7	32.2	14.5	169.76	182.03	12.27	7.2
8	14.2	10.3	202.97	201.52	1.45	0.7
9	68.1	14.5	145.49	149.49	4.00	2.7
10	60.7	2.0	198.12	165.61	32.51	16.4
11	189.2	33.9	11.30	24.96	13.66	120.9

**Segment 3 TPr value was an outlier and not entered into the model.*

N/A values indicate when discharge is greater in downstream value than upstream values.

Table 15: TP and TPr rankings with corresponding segments for each storm event and the average of the storm event.

Storm Event	Rank	TPr Concentration (µg/L)	Segment
6/22/2010	1	574.24	4
	2	102.89	11
	3	94.93	1
	4	86.68	7
	5	63.22	9
	6	58.71	5
	7	56.61	8
	8	24.54	10
	9	-43.61	3
	10	-48.82	2
	11	-643.85	6
7/13/2010	1	5025.34	3
	2	501.97	1
	3	337.17	2
	4	300.4	4
	5	294.75	5
	6	279.25	11
	7	263.58	7
	8	186.95	9
	9	146.42	10
	10	22.36	8
	11	N/A	6
7/21/2010	1	926.89	8
	2	711.67	10
	3	443.05	9
	4	371.94	11
	5	347.34	7
	6	103.81	5
	7	-279.74	1
	8	-319.41	4
	9	N/A	2
	10	N/A	3
	11	N/A	6
8/5/2010	1	1651.75	6
	2	559.47	4
	3	527.14	1
	4	110.31	10
	5	82.52	7
	6	77.86	8
	7	38.04	5
	8	14.52	9
	9	-255.73	2
	10	-340.83	11
	11	-609.63	3

Storm Event	Rank	TPr Concentration (µg/L)	Segment
8/16/2010	1	268.96	1
	2	257.23	3
	3	188.37	10
	4	134.65	2
	5	129.72	7
	6	100.17	8
	7	99.27	9
	8	70.29	5
	9	-288.61	4
	10	-527.12	11
	11	-953.98	6
9/13/2010	1	773.82	2
	2	595.95	4
	3	263.51	5
	4	183.3	6
	5	181.74	11
	6	108.71	7
	7	65.92	9
	8	33.93	8
	9	7.42	10
	10	-326.88	1
	11	N/A	3
Average	1	1157.33	3
	2	202.97	8
	3	198.12	10
	4	188.22	2
	5	169.76	7
	6	145.49	9
	7	138.19	5
	8	131.06	1
	9	99.72	4
	10	59.31	6
	11	11.3	11

Table 16: TP and TPr concentration rankings and corresponding segments from largest to smallest values.

TP Conc. (µg/L)	Segment	TPr Conc. (µg/L)	Segment
711.67	10	5025.34	3
505.34	8	1651.75	6
463.41	11	926.89	8
443.05	9	773.82	2
430.59	1	711.67	10
347.34	7	595.95	4
294.75	5	574.24	4
285.55	3	559.47	4
263.58	7	527.14	1
263.51	5	501.97	1
258.78	2	443.05	9
255.21	11	371.94	11
243.54	4	347.34	7
189.29	2	337.17	2
188.37	10	300.4	4
186.95	9	294.75	5
152.24	4	279.25	11
148.36	6	268.96	1
146.42	10	263.58	7
144.63	4	263.51	5
138.41	4	257.23	3
129.89	1	188.37	10
129.72	7	186.95	9
113.08	8	183.3	6
110.31	10	181.74	11
108.71	7	146.42	10
103.81	5	134.65	2
102.55	6	129.72	7
99.27	9	110.31	10
95.43	2	108.71	7
91.55	8	103.81	5
87.32	2	102.89	11
86.68	7	100.17	8
82.52	7	99.27	9
80.36	3	94.93	1
76.31	6	86.68	7
75.98	1	82.52	7
73.78	8	77.86	8
70.29	5	70.29	5
68.39	4	67.61	2
65.95	4	65.92	9
65.92	9	63.22	9
63.22	9	58.71	5
62.10	2	56.61	8
59.84	11	38.04	5
58.71	5	33.93	8
58.46	3	24.54	10
57.11	8	22.36	8
56.05	11	14.52	9
51.91	2	7.42	10
50.15	3	-43.61	3
45.34	1	-48.82	2
44.69	6	-255.73	2
44.33	6	-279.74	1
41.59	3	-288.61	4
40.80	1	-319.41	4
39.79	3	-326.88	1
38.04	5	-340.83	11
36.97	8	-527.12	11
36.39	6	-609.63	3
34.55	1	-643.85	6
31.43	11	-953.98	6
24.54	10	N/A	6
14.52	9	N/A	3
12.45	11	N/A	6
7.42	10	N/A	3

Table 17: Segmental frequency values with corresponding TPr concentrations

		Segmented TPr Concentration Values							
	Segment	**< 1 µg/L**	**1-50 µg/L**	**50-100 µg/L**	**100-250 µg/L**	**250-500 µg/L**	**500-750 µg/L**	**750-1000 µg/L**	**>1000 µg/L**
Frequency	**1**	II		I		I	II		
	2	II		I	I	I		I	
	3	II				I			I
	4	II				I	III		
	5		I	II	I	II			
	6	II			I				I
	7			II	I	II			
	8		II	II	I			I	
	9		I	III	I	I			
	10		II		II		I		
	11	II			II	II			

Figures

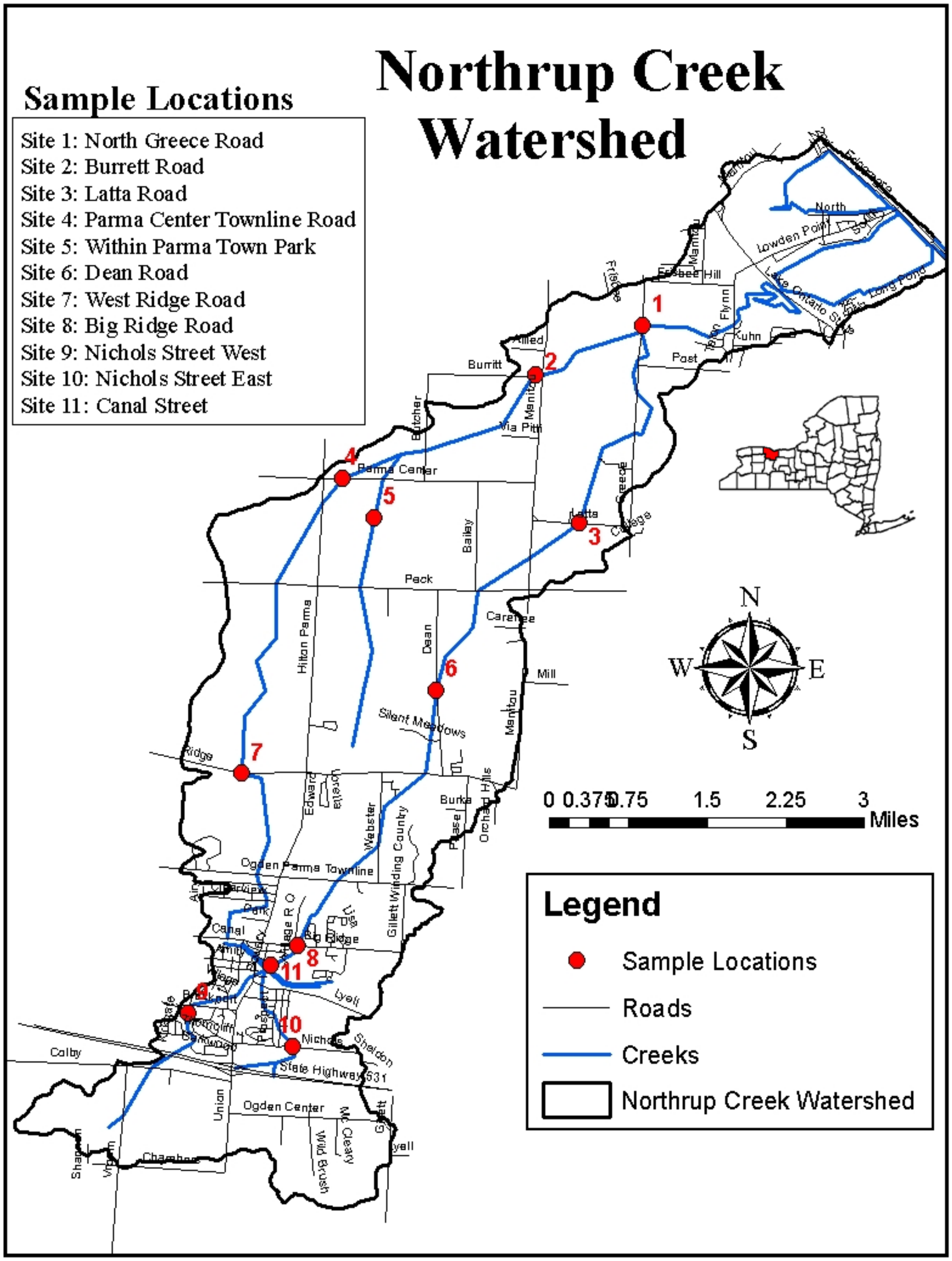


Figure 1: Northrup Creek location and study sampling locations.

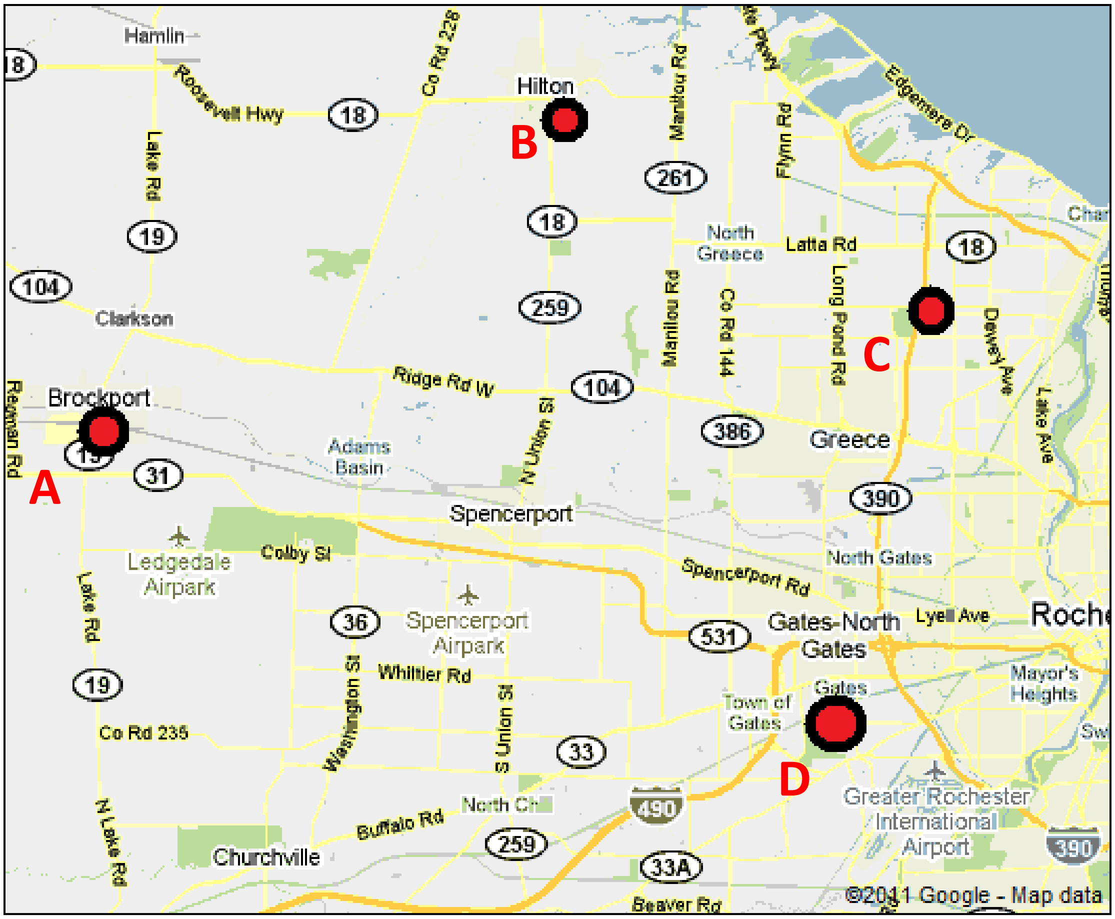


Figure 2: Precipitation measurement locations: Brockport Middle School (A), Quest Elementary School (B), Parkland Elementary School (C), and Gates/Chili High School (D).

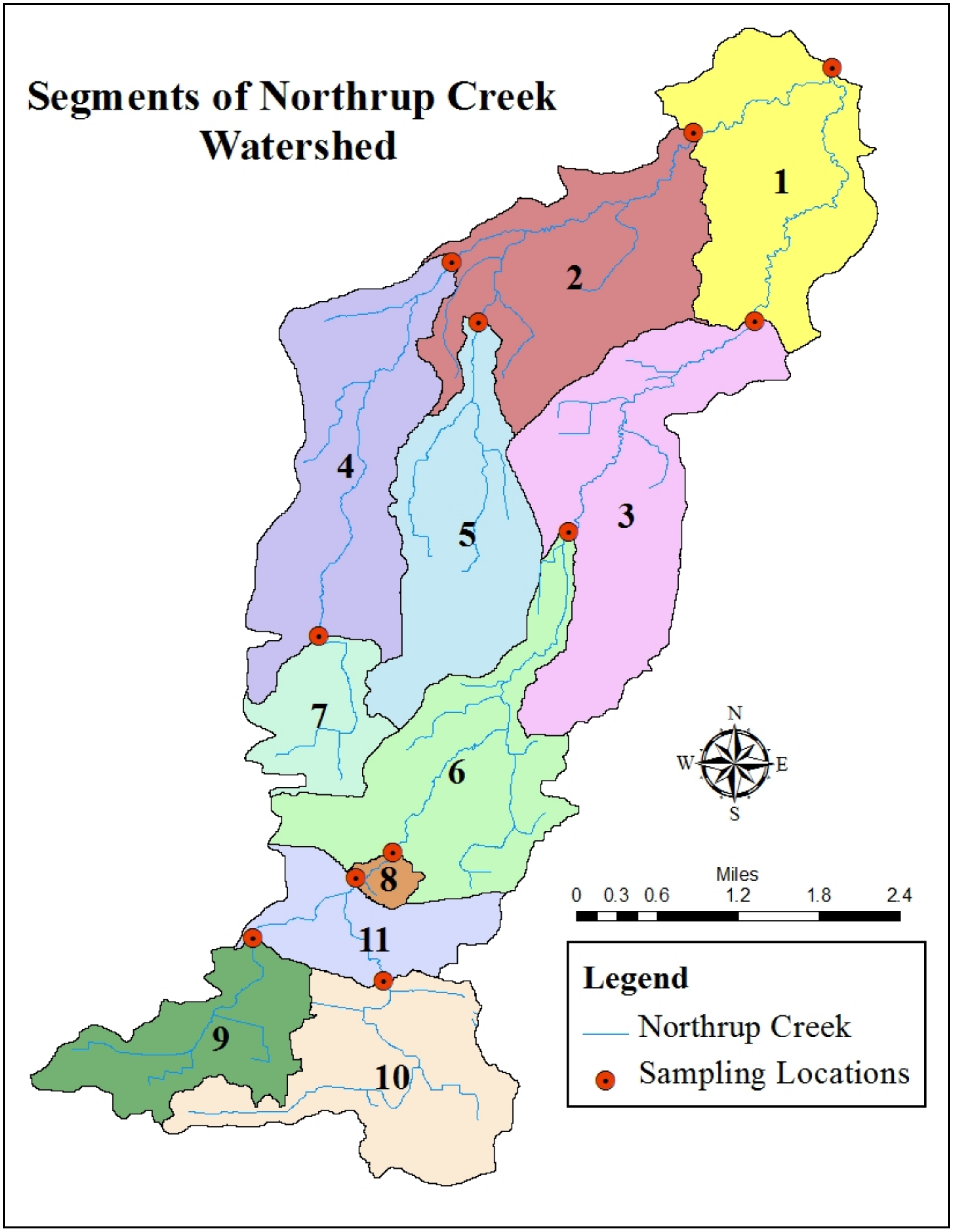


Figure 3: Location of the eleven segments in the Northrup Creek study.

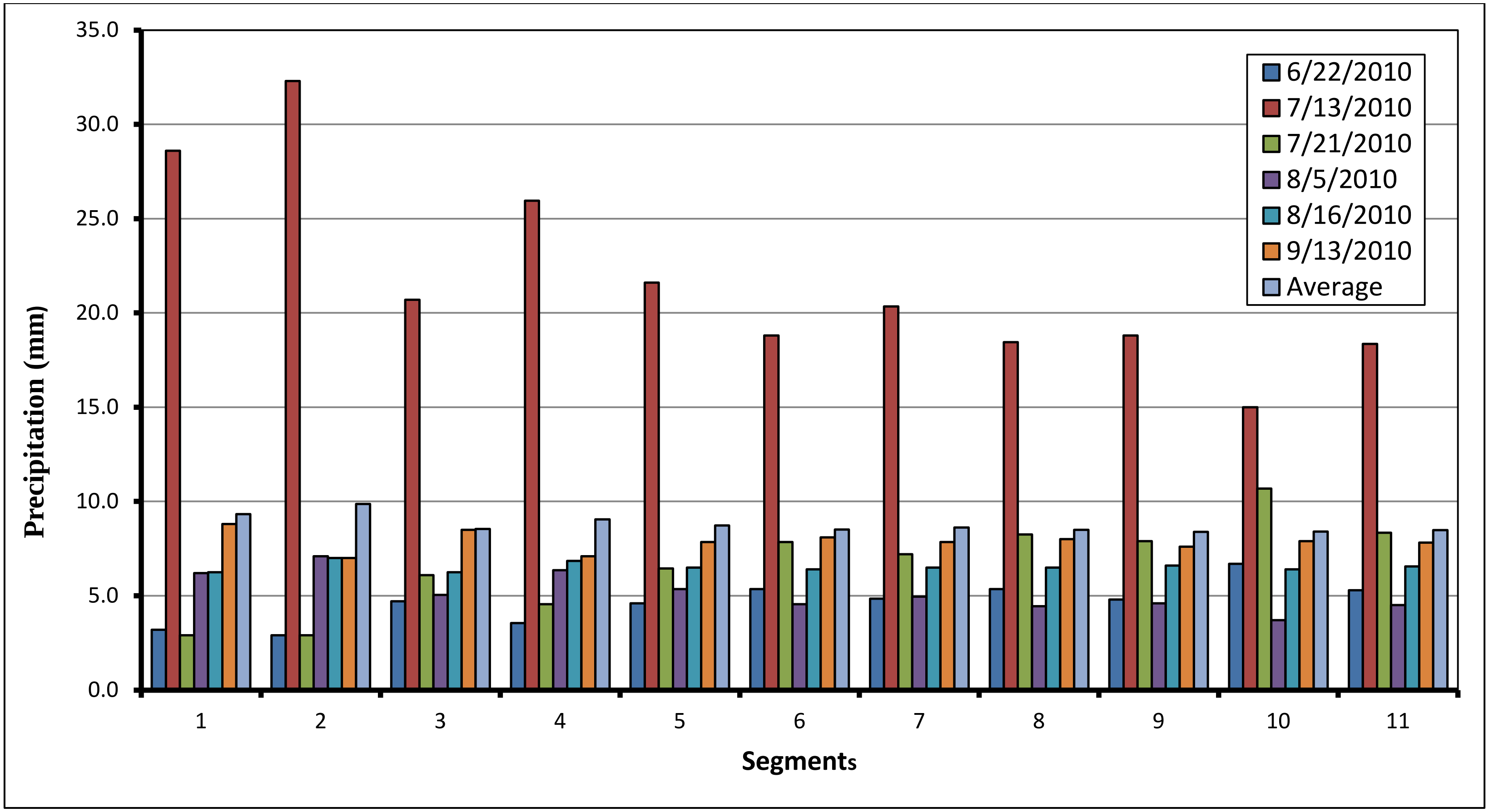


Figure 4: Storm event precipitation values for the eleven segments. Values are a calculated estimate of the total segmental area.

Appendix

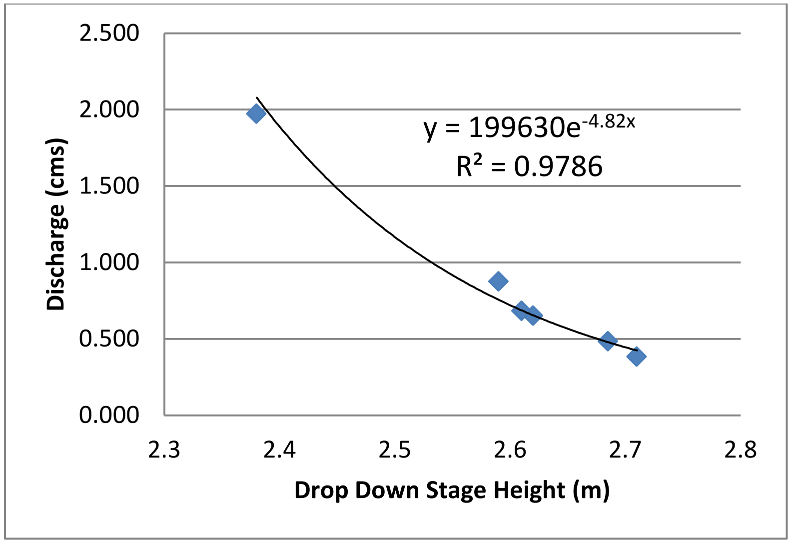
Appendix 1**:** USDA's National Engineering Handbook classification of hydrologic soil groups

Soil Hydrologic Group	Summary
Group A	This group contains soils that are mainly comprised of sandy gravel textures and have a high infiltration rate with low runoff potential.
Group B	This group contains soils that are comprised of between 50% to 90% sandy loams and 10% to 20% clay textures. They have a moderately high infiltration rate and moderately low run off potential.
Group C	This group contains soils that are comprised of less than 50% sandy loams and between 20% to 40% clay textures. They have a moderately low infiltration rate and moderately high runoff potential.
Group D	This group contains soils that are comprised of greater than 40% clay and less than 50% sandy loams. They have a very low infiltration rate and high runoff potential.

Appendix 2: Sample rating curve data

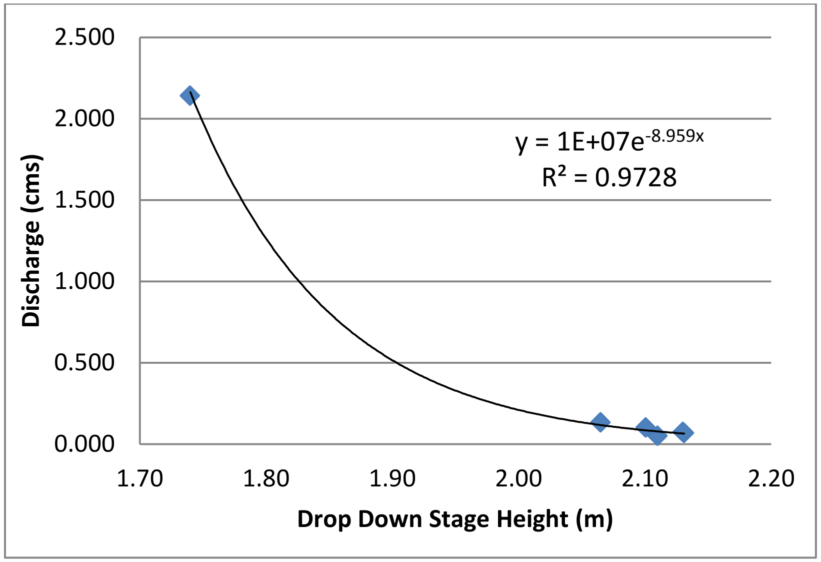
Sample Location One Data

Date	Stage Height (m)	Total Q (cms)
7/8/2010	2.71	0.384
8/23/2010	2.62	0.652
9/28/2010	2.685	0.483
10/1/2010	2.61	0.682
2/21/2011	2.59	0.876
3/22/2011	2.38	1.972



Sample Location Two Data

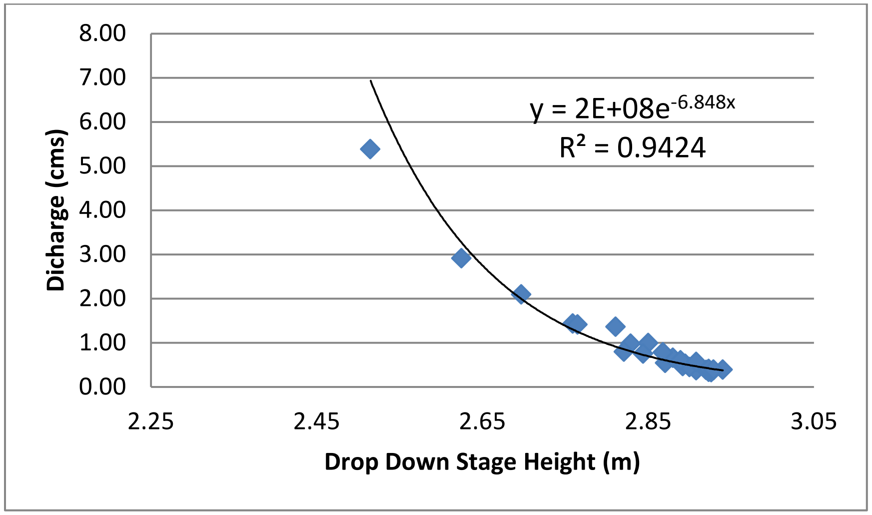
Date	Staff Height (m)	Total Q (cms)
5/10/2010	2.10	0.102
5/17/2010	2.13	0.068
7/8/2010	2.11	0.050
8/23/2010	2.13	0.074
10/1/2010	2.07	0.132
3/22/2011	1.74	2.141



Sample Location Three Data

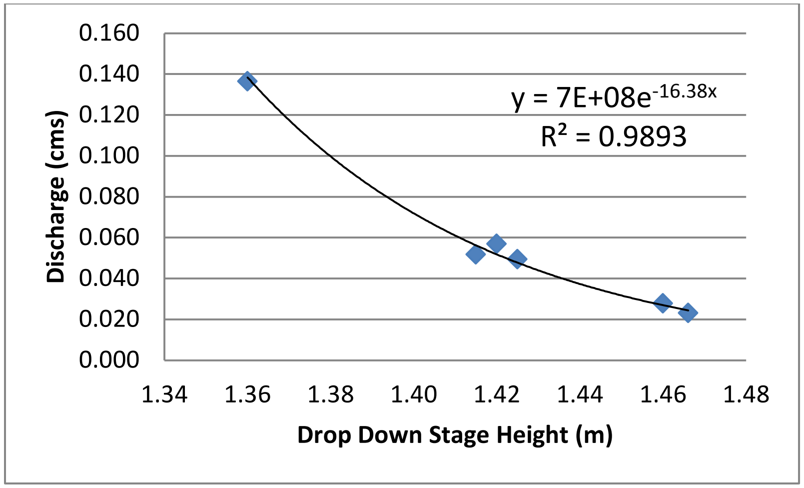
Date	Staff Height (m)	Total Q (cms)
1/13/2005	2.77	1.410
11/30/2005	2.76	1.430
3/20/2008	2.63	2.910
5/29/2009	2.89	0.470
2/27/2010	2.70	2.090
5/10/2010	2.92	0.390
5/17/2010	2.87	0.540
6/11/2010	2.91	0.380
7/8/2010	2.94	0.390
7/16/2010	2.92	0.340
8/23/2010	2.88	0.660
9/28/2010	2.91	0.410
10/1/2010	2.90	0.520
10/6/2010	2.89	0.600

Date	Staff Height (m)	Total Q (cms)
10/21/2010	2.90	0.450
11/12/2010	2.93	0.330
3/10/2011	2.52	5.380
4/21/2011	2.83	0.970
5/27/2011	2.81	1.360
6/6/2011	2.91	0.560
8/11/2011	2.93	0.380
8/25/2011	2.82	0.800
10/17/2011	2.92	0.410
11/4/2011	2.92	0.370
12/9/2011	2.85	0.990
2/17/2012	2.84	0.750
4/27/2012	2.87	0.780
6/8/2012	2.93	0.390



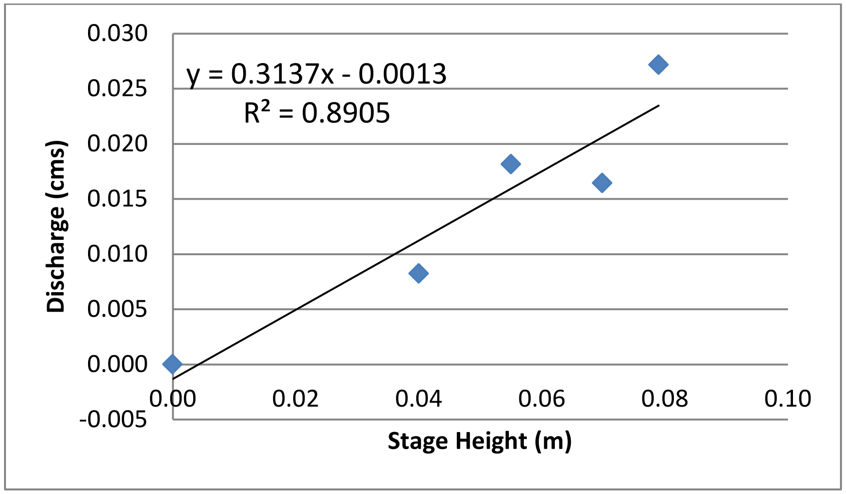
Sample Location Four Data

Date	Staff Height (m)	Total Q (cms)
5/17/2010	1.47	0.023
7/8/2010	1.42	0.057
8/22/2010	1.415	0.052
8/23/2010	1.46	0.028
10/1/2010	1.43	0.049
2/21/2011	1.36	0.136



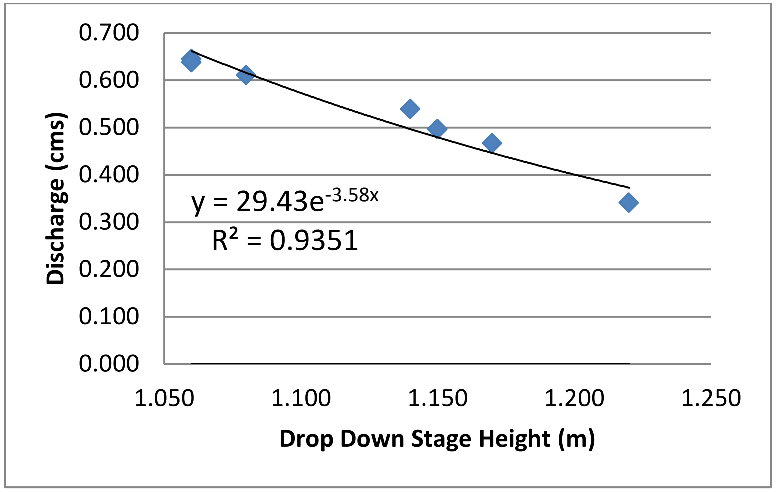
Sample Location Five Data

Date	Staff Height (ft)	Total Q (cfs)
5/10/2010	0.08	0.027
5/17/2010	0.07	0.016
7/8/2010	0.00	0.000
8/22/2010	0.04	0.008
8/23/2010	0.05	0.018



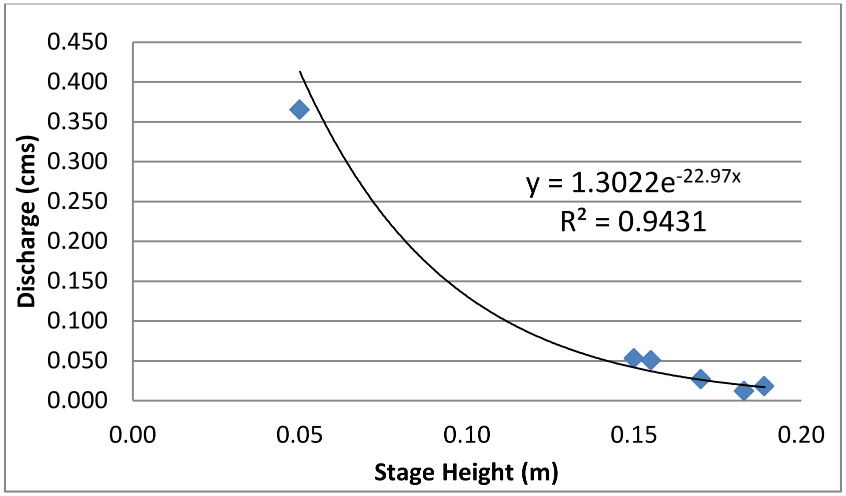
Sample Location Six Data

Date	Staff Height (m)	Total Q (cms)
5/10/2010	1.14	0.539
5/17/2010	1.17	0.467
7/8/2010	1.22	0.341
8/22/2010	1.06	0.645
8/23/2010	1.08	0.610
3/2/2011	1.15	0.496
2/21/2011	1.06	0.638



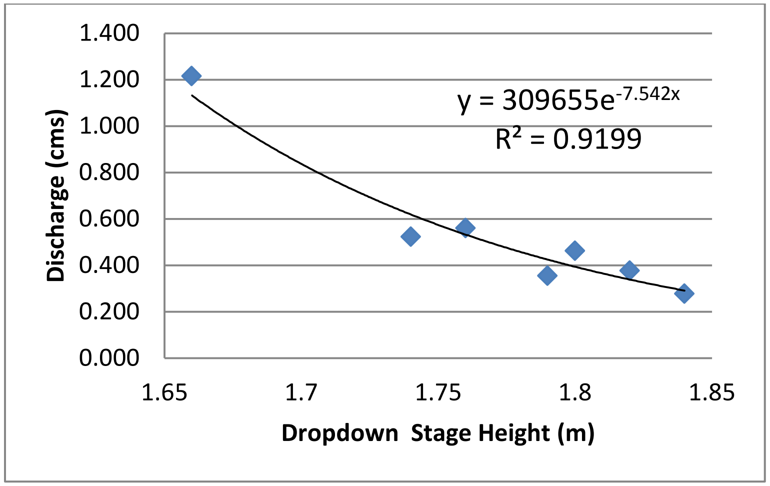
Sample Location Seven Data

Date	Staff Height (m)	Total Q (cms)
5/10/2010	0.18	0.012
5/17/2010	0.19	0.018
7/8/2010	0.16	0.050
8/22/2010	0.17	0.027
8/23/2010	0.15	0.053
2/28/2010	0.05	0.365



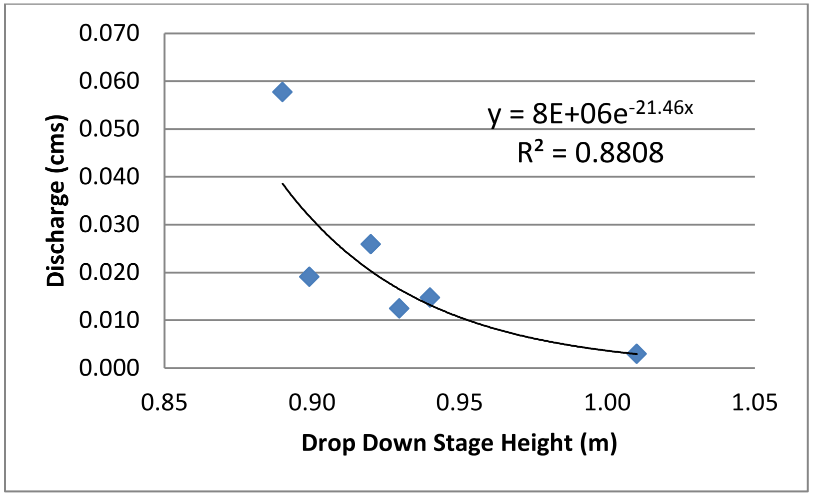
Sample Location Eight Data

Date	Staff Height (m)	Total Q (cms)
5/10/2010	1.74	0.523
5/17/2010	1.79	0.355
7/8/2010	1.82	0.377
8/22/2010	1.8	0.463
8/23/2010	1.76	0.561
2/21/2011	1.84	0.277
3/6/2011	1.66	1.215



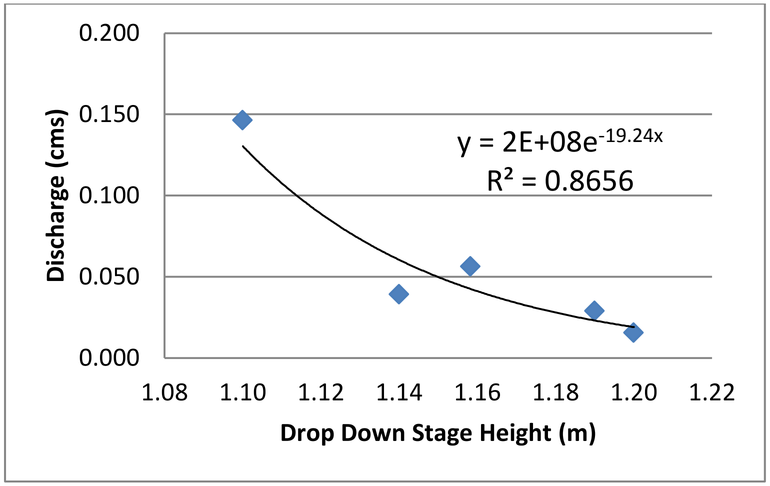
Sample Location Nine Data

Date	Staff Height (m)	Total Q (cms)
5/10/2010	0.90	0.019
5/17/2010	0.93	0.012
7/8/2010	1.01	0.003
8/22/2010	0.94	0.015
8/23/2010	0.92	0.026
2/21/2011	0.89	0.058



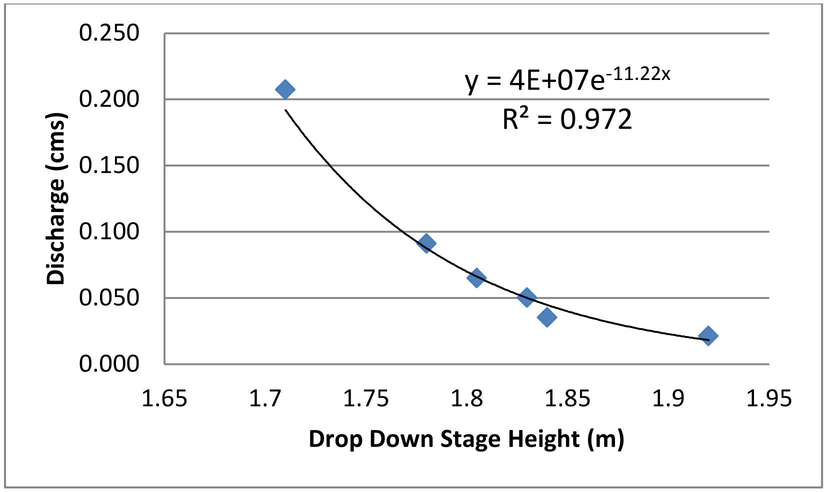
Sample Location Ten Data

Date	Staff Height (m)	Total Q (cms)
5/17/2010	1.16	0.056
7/8/2010	1.20	0.016
8/22/2010	1.19	0.029
9/28/2010	1.10	0.146
2/21/2011	1.14	0.039



Sample Location Eleven Data

Date	Staff Height (m)	Total Q (cms)
7/8/2010	1.92	0.021
8/22/2010	1.83	0.050
8/23/2010	1.78	0.091
9/28/2010	1.84	0.035
10/1/2010	1.805	0.065
2/21/2011	1.71	0.207



Appendix 3: Raw sampling and calculated values among sampling events.

Sample Segment	Date	Rain Event Type	TP (μg/L)	Stage Measurement (m)	Discharge (L/sec)	TP Loading (mg/sec)	TP Runoff (μg/L)
1	6/22/2010	Storm Event	45.34	2.69	466.93	21.17	94.93
2	6/22/2010	Storm Event	62.10	2.18	32.96	2.05	-48.82
3	6/22/2010	Storm Event	41.59	2.92	413.82	17.21	-43.61
4	6/22/2010	Storm Event	144.63	1.50	14.94	2.16	574.24
5	6/22/2010	Storm Event	58.71	0.03	7.11	0.42	58.71
6	6/22/2010	Storm Event	44.33	1.20	400.92	17.77	-643.85
7	6/22/2010	Storm Event	86.68	0.20	13.17	1.14	86.68
8	6/22/2010	Storm Event	57.11	1.80	393.61	22.48	56.61
9	6/22/2010	Storm Event	63.22	0.95	11.20	0.71	63.22
10	6/22/2010	Storm Event	24.54	1.18	27.62	0.68	24.54
11	6/22/2010	Storm Event	59.84	1.81	60.58	3.63	102.89
1	7/8/2010	Baseflow	78.12	2.71	424.02	33.12	15152.45
2	7/8/2010	Baseflow	50.69	2.11	61.70	3.13	118.82
3	7/8/2010	Baseflow	21.69	2.94	360.85	7.83	1249.86
4	7/8/2010	Baseflow	42.94	1.42	55.41	2.38	-99.99
5	7/8/2010	Baseflow	37.17	1.67	No Flow	N/A	37.17
6	7/8/2010	Baseflow	19.11	1.23	360.10	6.88	-238.56
7	7/8/2010	Baseflow	113.95	0.16	37.02	4.22	113.95
8	7/8/2010	Baseflow	35.55	1.82	338.50	12.03	32.03
9	7/8/2010	Baseflow	83.50	1.01	3.09	0.26	83.50
10	7/8/2010	Baseflow	14.49	1.20	18.79	0.27	14.49
11	7/8/2010	Baseflow	99.58	1.92	17.63	1.76	-288.24
1	7/13/2010	Storm Event	430.59	2.38	2080.53	895.85	501.97
2	7/13/2010	Storm Event	258.78	1.97	216.29	55.97	337.17
3	7/13/2010	Storm Event	285.55	2.91	443.15	126.54	5025.34
4	7/13/2010	Storm Event	243.54	1.38	106.69	25.98	300.40
5	7/13/2010	Storm Event	294.75	0.07	20.66	6.09	294.75
6	7/13/2010	Storm Event	148.36	1.18	430.68	63.90	N/A
7	7/13/2010	Storm Event	263.58	0.09	164.76	43.43	263.58
8	7/13/2010	Storm Event	113.08	1.70	836.79	94.62	22.36
9	7/13/2010	Storm Event	186.95	0.91	26.42	4.94	186.95
10	7/13/2010	Storm Event	146.42	1.16	40.58	5.94	146.42
11	7/13/2010	Storm Event	255.21	1.66	326.02	83.20	279.25

Appendix 3 cont.

Sample Segment	Date	Rain Event Type	TP (μg/L)	Stage Measurement (m)	Discharge (L/sec)	TP Loading (mg/sec)	TP Runoff (μg/L)
1	7/21/2010	Storm Event	40.8	2.68	489.99	19.99	-279.74
2	7/21/2010	Storm Event	51.91	2.13	51.58	2.68	N/A
3	7/21/2010	Storm Event	58.46	2.92	413.82	24.19	N/A
4	7/21/2010	Storm Event	65.95	1.32	285.07	18.80	-319.41
5	7/21/2010	Storm Event	103.81	0.02	4.97	0.52	103.81
6	7/21/2010	Storm Event	76.31	1.19	415.54	31.71	N/A
7	7/21/2010	Storm Event	347.34	0.09	164.76	57.23	347.34
8	7/21/2010	Storm Event	505.34	1.50	3781.85	1911.12	926.89
9	7/21/2010	Storm Event	443.05	0.72	1558.54	690.51	443.05
10	7/21/2010	Storm Event	711.67	1.02	599.91	426.94	711.67
11	7/21/2010	Storm Event	463.41	1.45	3439.72	1594.00	371.94
1	8/5/2010	Storm Event	129.89	2.67	526.72	68.42	527.14
2	8/5/2010	Storm Event	95.43	2.12	56.42	5.38	-255.73
3	8/5/2010	Storm Event	80.36	2.92	413.82	33.25	-609.63
4	8/5/2010	Storm Event	138.41	1.43	47.04	6.51	559.47
5	8/5/2010	Storm Event	38.04	0.02	4.97	0.19	38.04
6	8/5/2010	Storm Event	102.55	1.20	400.92	41.11	1651.75
7	8/5/2010	Storm Event	82.52	0.15	41.53	3.43	82.52
8	8/5/2010	Storm Event	73.78	1.80	393.61	29.04	77.86
9	8/5/2010	Storm Event	14.52	0.97	7.29	0.11	14.52
10	8/5/2010	Storm Event	110.31	1.19	22.78	2.51	110.31
11	8/5/2010	Storm Event	31.43	1.86	34.57	1.09	-340.83
1	8/16/2010	Storm Event	75.98	2.66	539.57	41.00	268.96
2	8/16/2010	Storm Event	87.32	2.16	39.43	3.44	134.65
3	8/16/2010	Storm Event	50.15	2.91	443.15	22.22	257.23
4	8/16/2010	Storm Event	68.39	1.47	24.43	1.67	-288.61
5	8/16/2010	Storm Event	70.29	0.01	1.84	0.13	70.29
6	8/16/2010	Storm Event	36.39	1.19	415.54	15.12	-953.98
7	8/16/2010	Storm Event	129.72	0.18	20.85	2.70	129.72
8	8/16/2010	Storm Event	91.55	1.80	393.61	36.04	100.17
9	8/16/2010	Storm Event	99.27	0.97	7.29	0.72	99.27
10	8/16/2010	Storm Event	188.37	1.19	22.78	4.29	188.37
11	8/16/2010	Storm Event	12.45	1.85	38.67	0.48	-527.12

Appendix 3 cont.

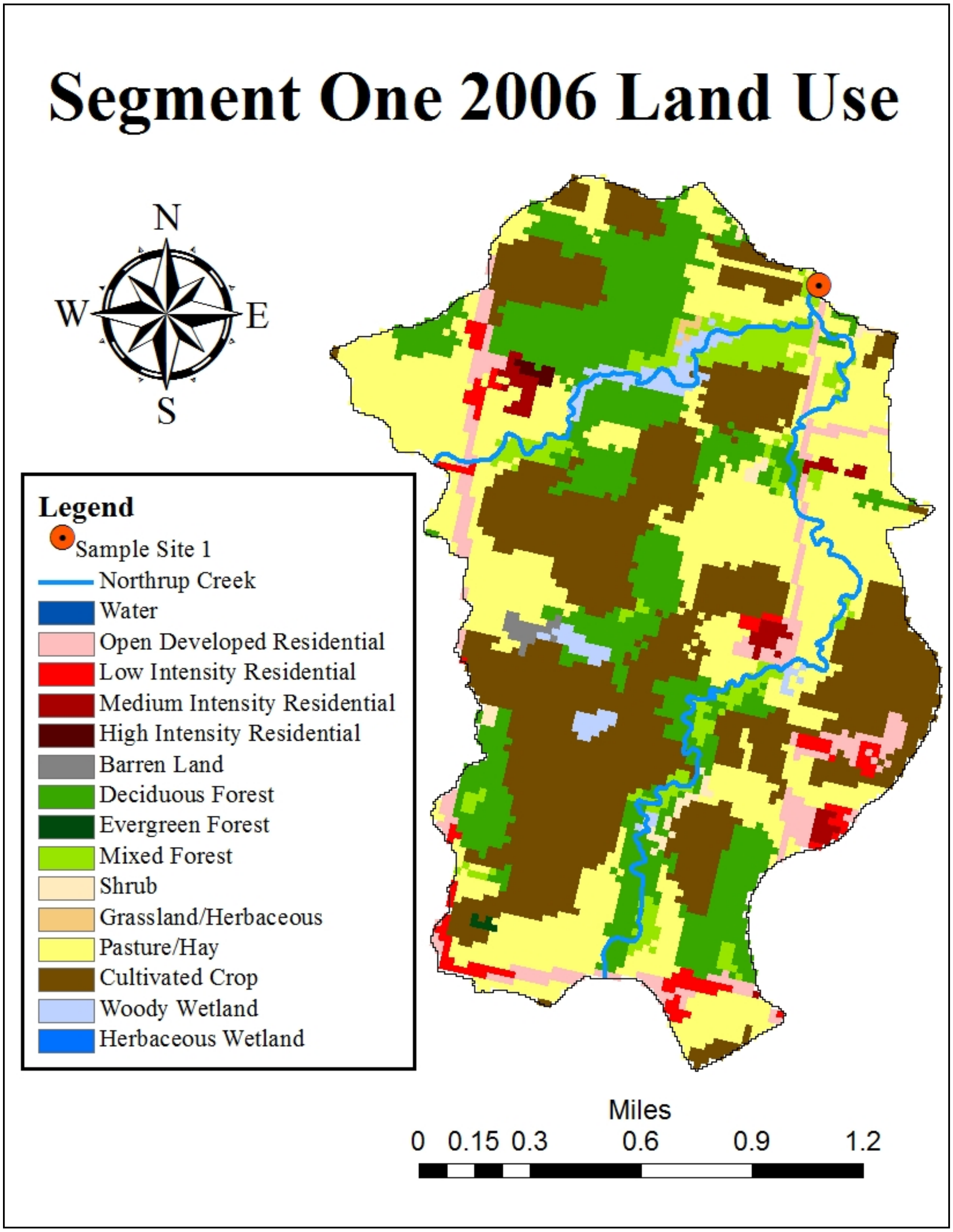
Sample Segment	Date	Rain Event Type	TP (μg/L)	Stage Measurement (m)	Discharge (L/sec)	TP Loading (mg/sec)	TP Runoff (μg/L)
1	9/2/2010	Baseflow	43.94	2.72	404.07	17.76	N/A
2	9/2/2010	Baseflow	112.63	2.25	18.41	2.07	217.74
3	9/2/2010	Baseflow	120.39	2.93	386.43	46.52	N/A
4	9/2/2010	Baseflow	65.25	1.15	12.69	0.83	-43.93
5	9/2/2010	Baseflow	13.57	1.67	No Flow	N/A	37.60
6	9/2/2010	Baseflow	37.60	1.20	400.92	15.07	355.16
7	9/2/2010	Baseflow	109.23	0.21	10.47	1.14	109.23
8	9/2/2010	Baseflow	19.10	1.81	379.05	7.24	18.24
9	9/2/2010	Baseflow	38.29	1.03	2.01	0.08	38.29
10	9/2/2010	Baseflow	72.79	1.22	14.08	1.03	72.79
11	9/2/2010	Baseflow	40.11	1.94	14.90	0.60	N/A
1	9/13/2010	Storm Event	34.55	2.70	444.96	15.37	-326.88
2	9/13/2010	Storm Event	189.29	2.25	17.60	3.33	773.82
3	9/13/2010	Storm Event	39.79	2.92	413.82	16.47	N/A
4	9/13/2010	Storm Event	152.24	1.50	16.22	2.47	595.95
5	9/13/2010	Storm Event	263.51	0.01	0.27	0.07	263.51
6	9/13/2010	Storm Event	44.69	1.19	415.54	18.57	183.30
7	9/13/2010	Storm Event	108.71	0.20	14.77	1.61	108.71
8	9/13/2010	Storm Event	36.97	1.80	393.61	14.55	33.93
9	9/13/2010	Storm Event	65.92	0.93	17.20	1.13	65.92
10	9/13/2010	Storm Event	7.42	1.18	27.62	0.20	7.42
11	9/13/2010	Storm Event	56.05	1.82	54.15	3.04	181.74
1	Average	Storm Event	126.19	2.63	758.12	176.97	131.06
2	Average	Storm Event	124.14	2.14	69.05	12.14	188.22
3	Average	Storm Event	92.65	2.92	423.59	39.98	1157.33
4	Average	Storm Event	135.53	1.43	82.40	9.60	99.72
5	Average	Storm Event	138.19	0.03	6.64	1.24	138.19
6	Average	Storm Event	75.44	1.19	413.19	31.36	59.31
7	Average	Storm Event	169.76	0.15	69.97	18.26	169.76
8	Average	Storm Event	146.31	1.73	1032.18	351.31	202.97
9	Average	Storm Event	145.49	0.91	271.32	116.35	145.49
10	Average	Storm Event	198.12	1.15	123.55	73.43	198.12
11	Average	Storm Event	146.40	1.74	658.95	280.91	11.30

Appendix 4: Land use cover descriptions

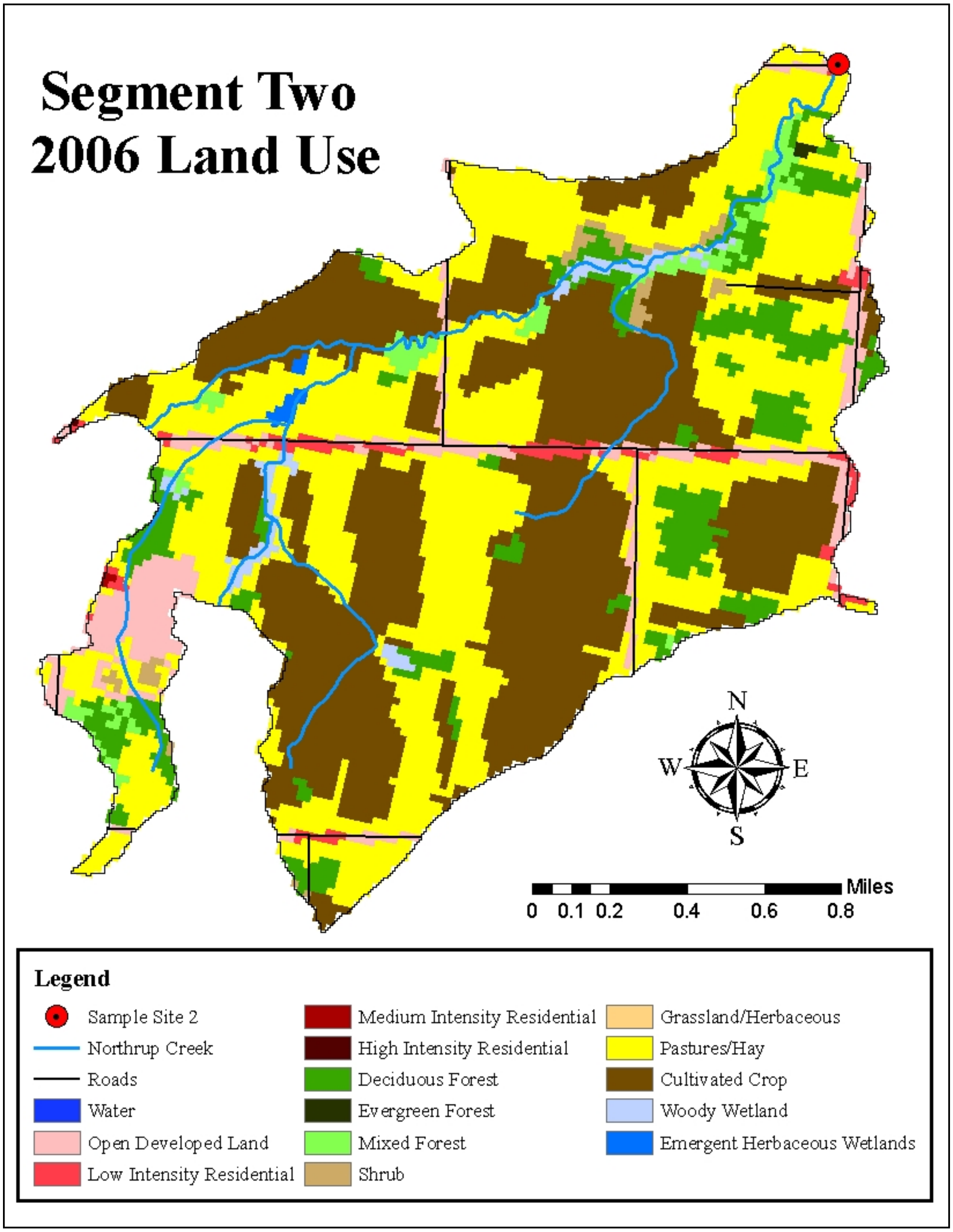
Land Use Type	Description
Open Water	Areas of open water with less than 25% cover, vegetation or soil
Developed Open Space	Areas with a mixture of some constructed materials, but mainly vegetation in the form of lawn grasses and contains less than 20% of impervious surfaces. These areas are commonly used as large-lot single family housing units, parks, golf courses.
Developed Low Intensity	Areas with a mixture of constructed materials and vegetation with impervious surfaces accounting for 20-49% of the total cover. These areas include single-family housing units.
Developed Medium Intensity	Areas with a mixture of constructed materials and vegetation with impervious surfaces accounting for 50-79% of the total cover. These areas include single-family housing units.
Developed High Intensity	Areas with highly developed areas where people reside or work in high numbers with impervious surface account for 80-100% of the total cover. These areas include apartment complexes, row houses, and commercial/industrial lands.
Barren Land	Areas containing bedrock, gravel pits, and other earthen material. Vegetation accounts for less than 15% of the total cover.
Deciduous Forest	Areas dominated by trees greater than five meters tall and account for greater than 20% of the total vegetation cover. Greater than 70% of the tree species shed foliage in response to seasonal change.
Evergreen Forest	Areas dominated by trees greater than five meters tall and account for greater than 20% of the total vegetation cover. Greater than 75% of tree species maintain their canopy and leaves all year.
Mixed Forest	Areas dominated by trees greater than five meters tall and account for greater than 20% of the total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of the total tree cover.
Shrub	Areas dominated by shrubs less than five meters tall with a canopy greater than 20% of total vegetation. These include true shrubs and young trees.
Grassland/Herbaceous	Areas dominated by graminoid or herbaceous vegetation greater than 80% of total vegetation. These areas can be utilized for grazing and are not subjected to intensive management such as tilling.
Pasture/Hay	Areas of grasses and legumes mixtures planted for livestock grazing or production of seed or hay crops, typically on a perennial cycle. Pastures account for greater than 20% of the total vegetation.
Cultivated Crop	Areas used for production of annual crops such as corn, soybeans, vegetables. These lands also include vineyards, orchards, and all land being actively tilled. Crop vegetation accounts for greater than 20% of total vegetation.
Woody Wetland	Areas where forest or shrub land accounts for greater than 20% of vegetative cover with the soil or substrate is periodically saturated or covered with water.
Emergent Herbaceous Wetlands	Areas were perennial herbaceous vegetation account for greater than 80% of the vegetative cover with the soil or substrate is periodically saturated or covered with water.

National Land Cover Database. 2011.

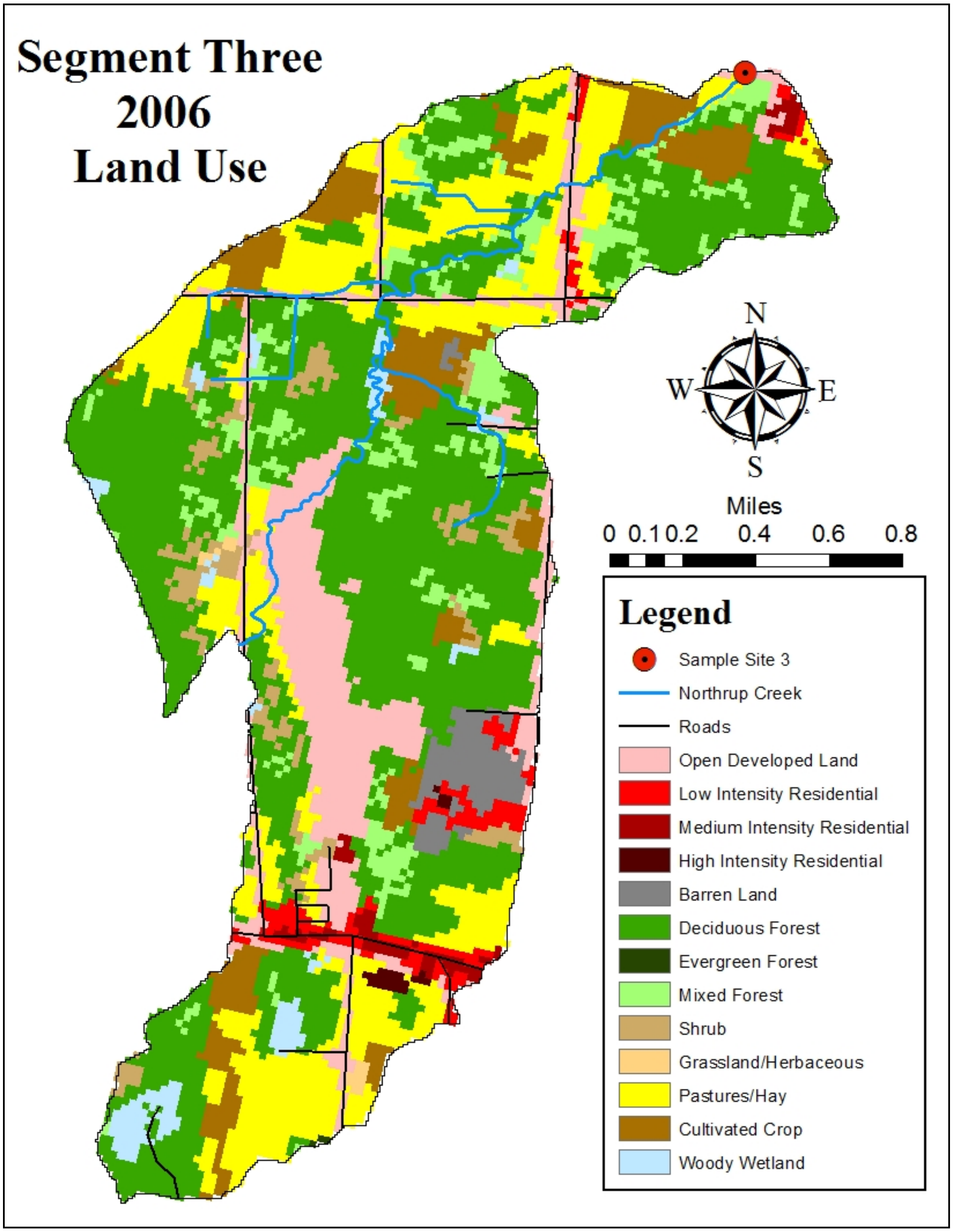
Appendix 5: Segmental land use maps



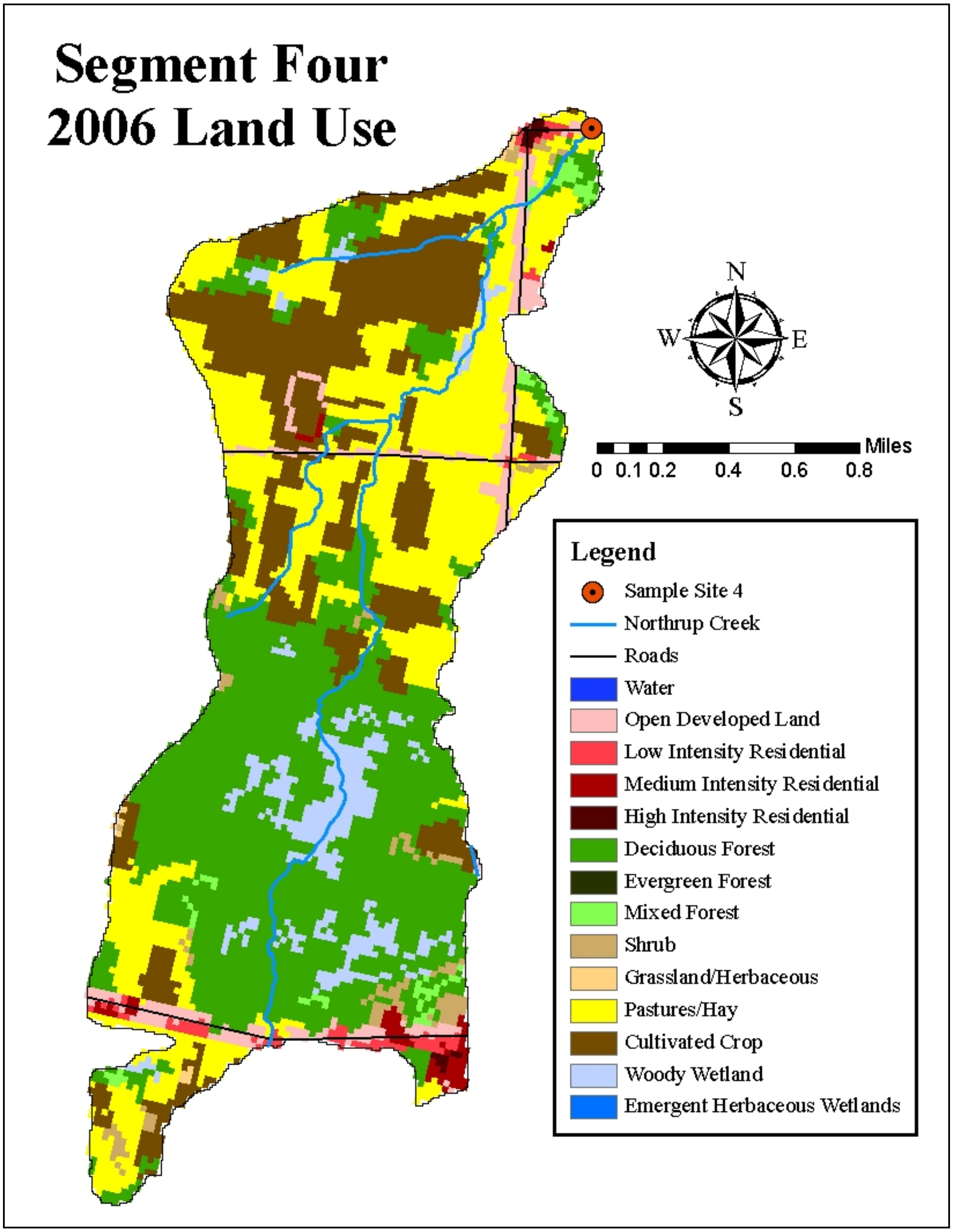
Appendix 5 cont.



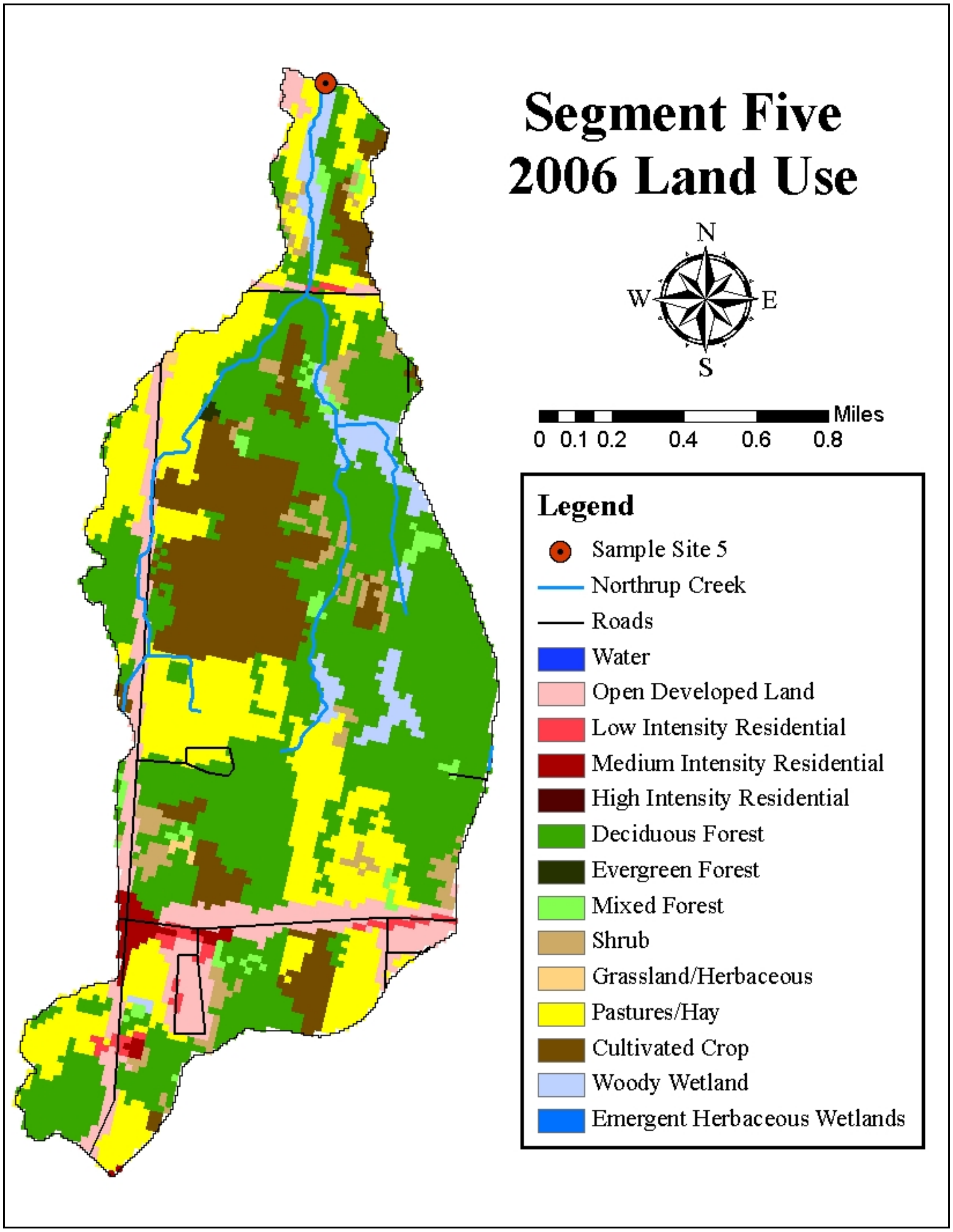
Appendix 5 cont.



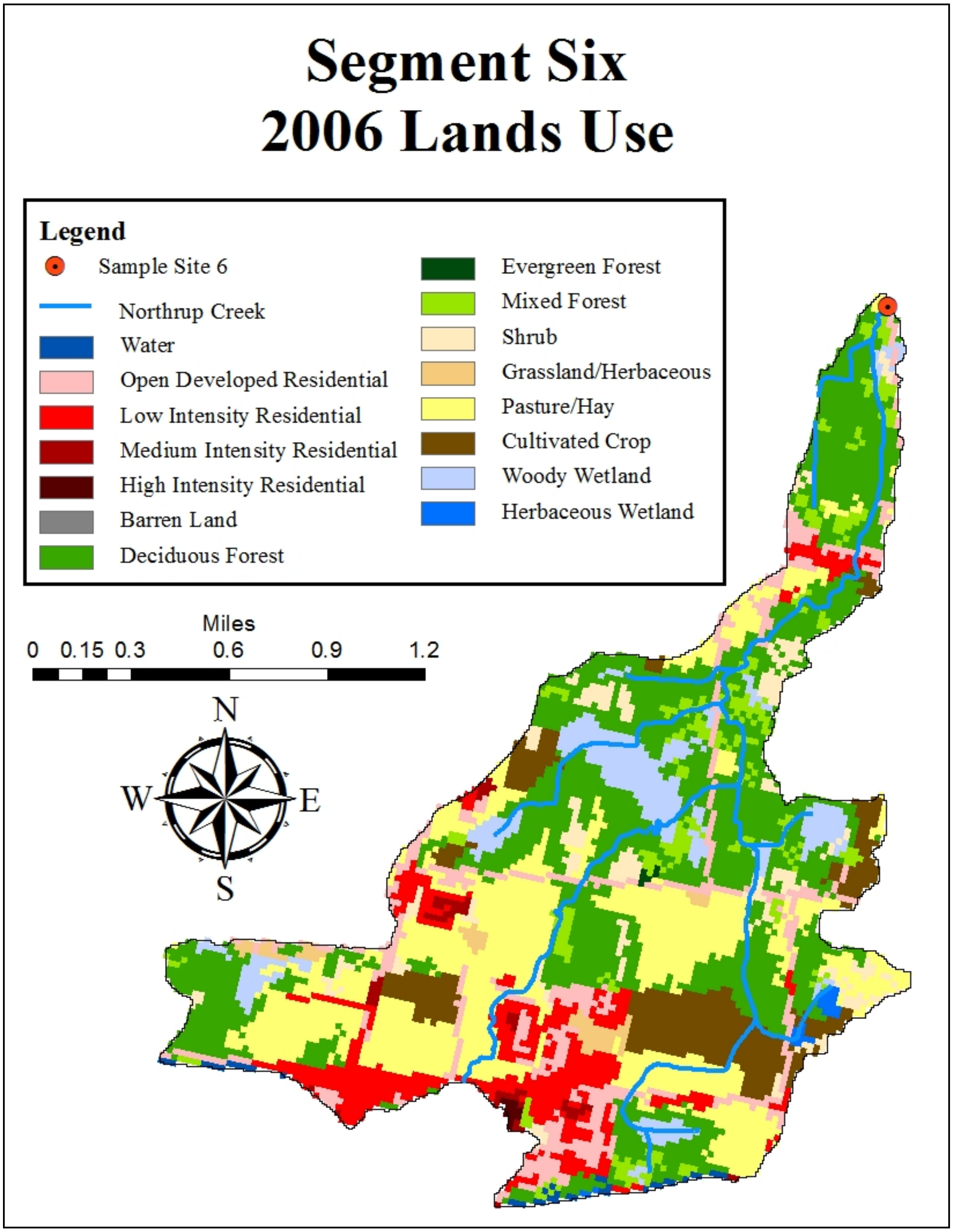
Appendix 5 cont.



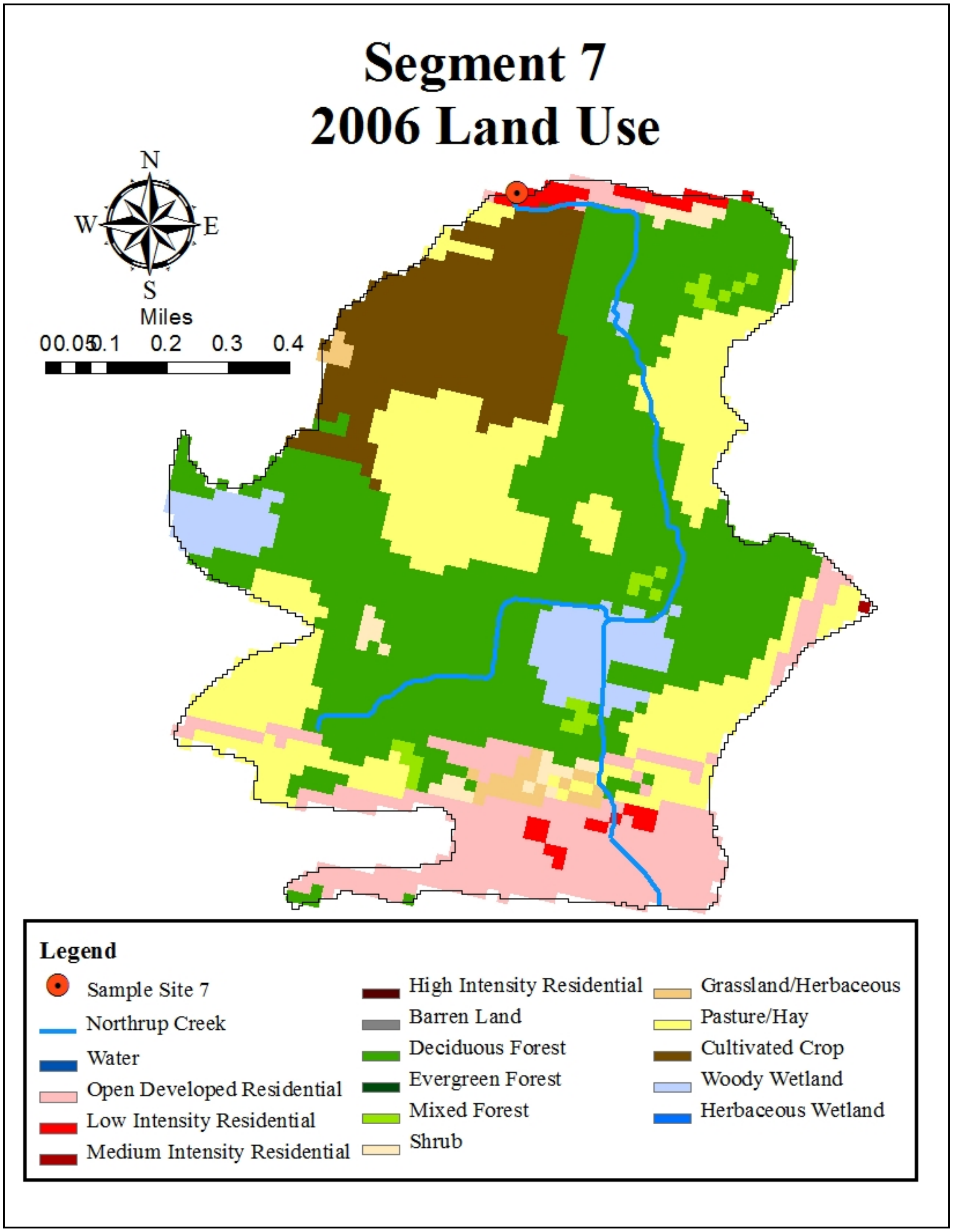
Appendix 5 cont.



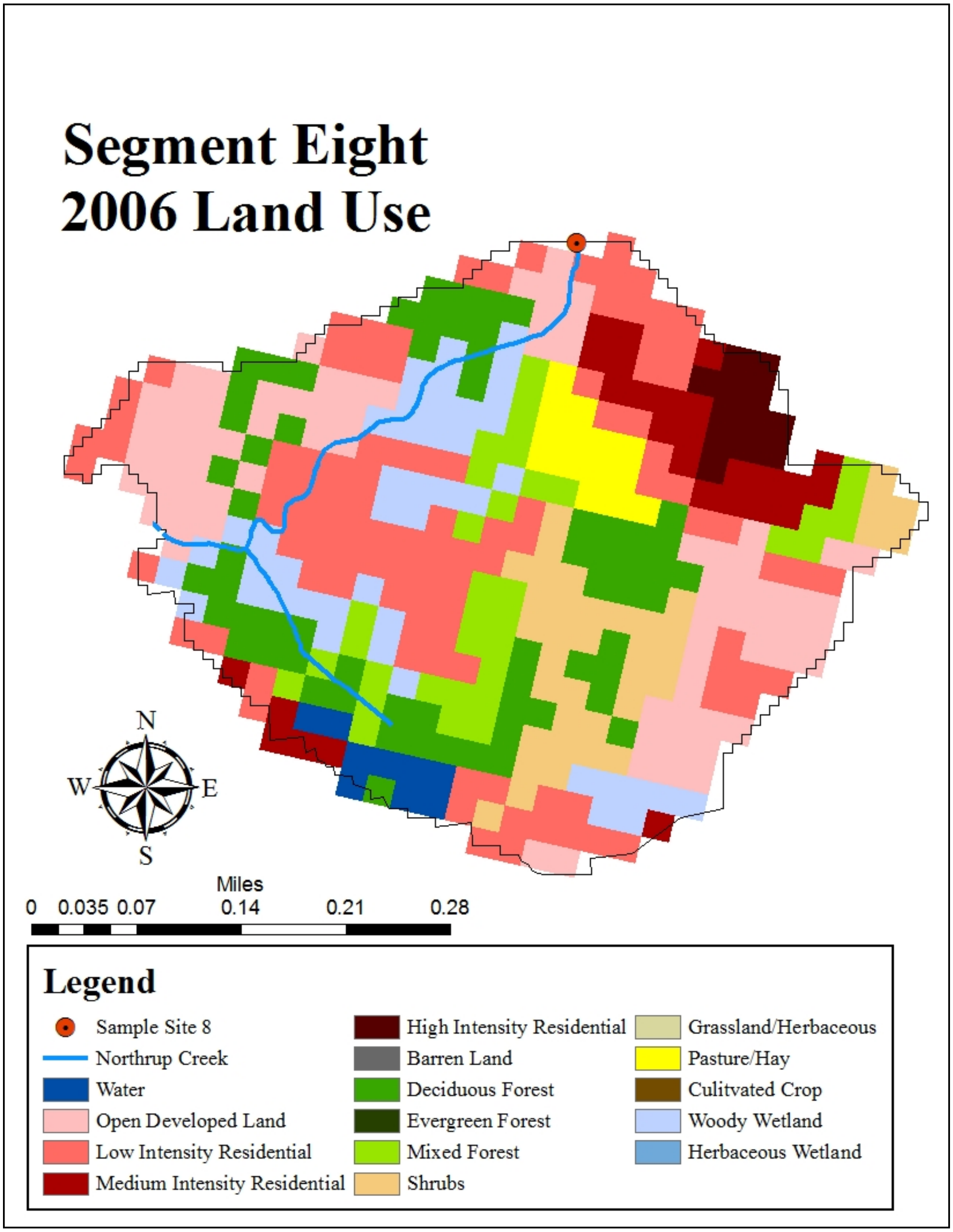
Appendix 5 cont.



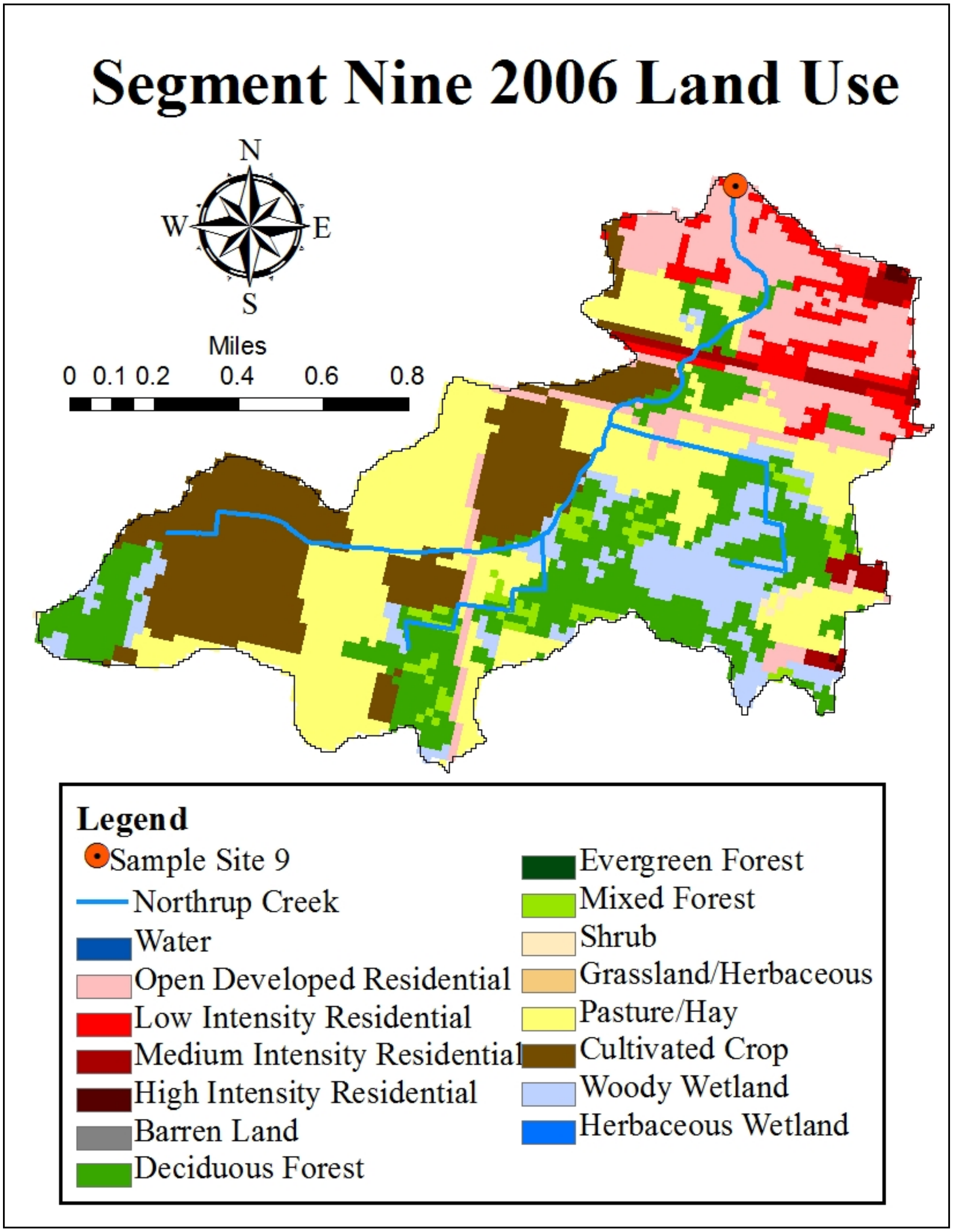
Appendix 5 cont.



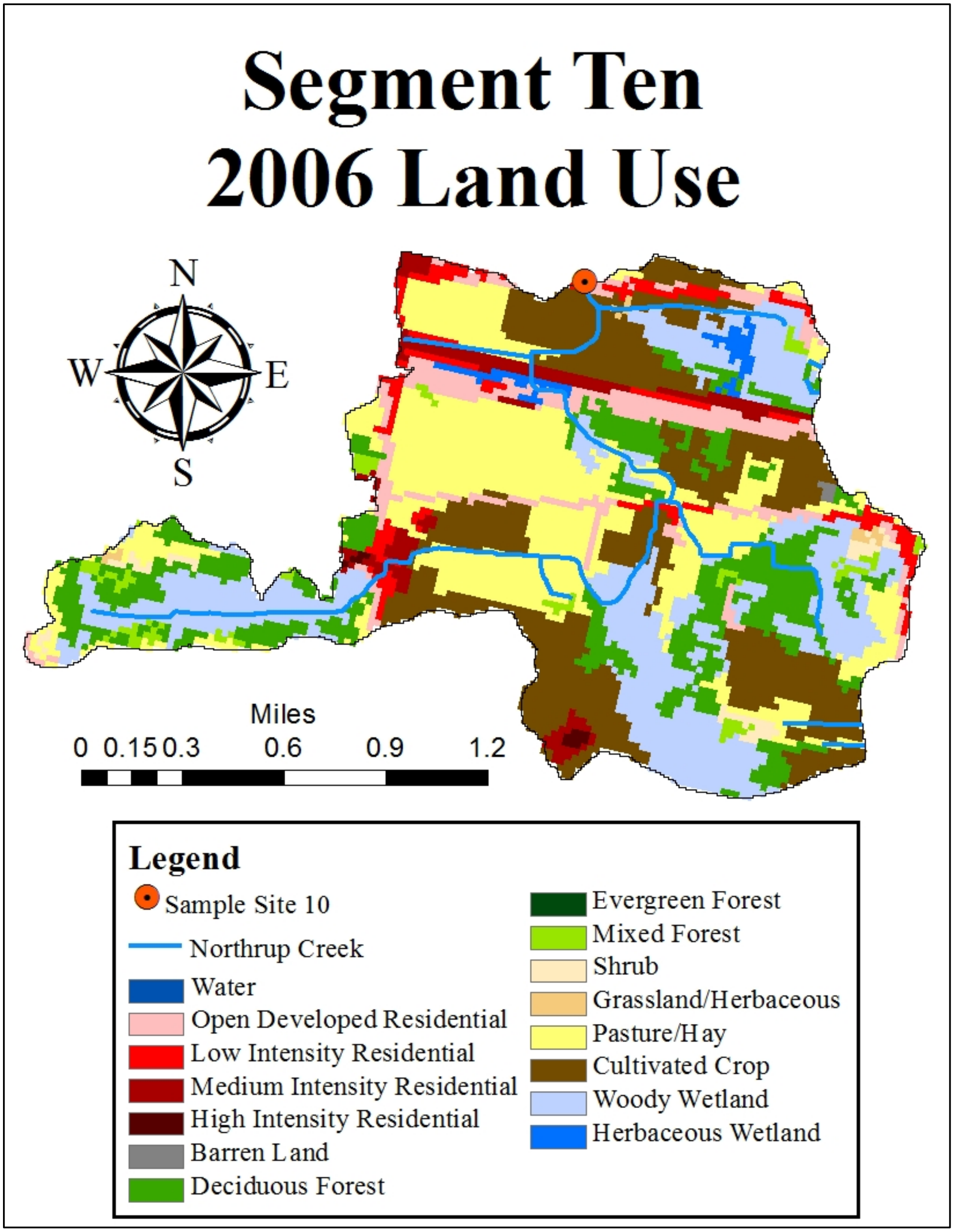
Appendix 5 cont.



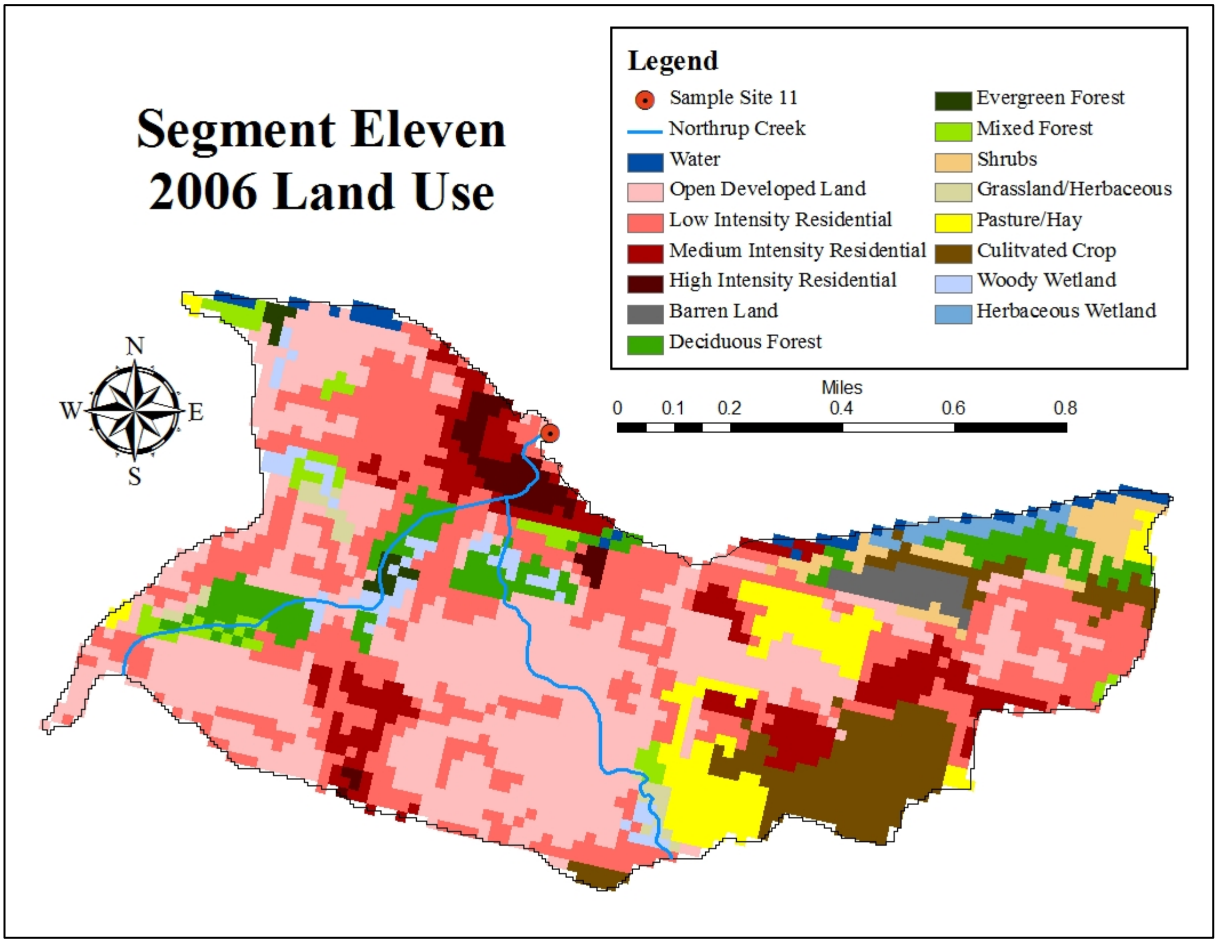
Appendix 5 cont.



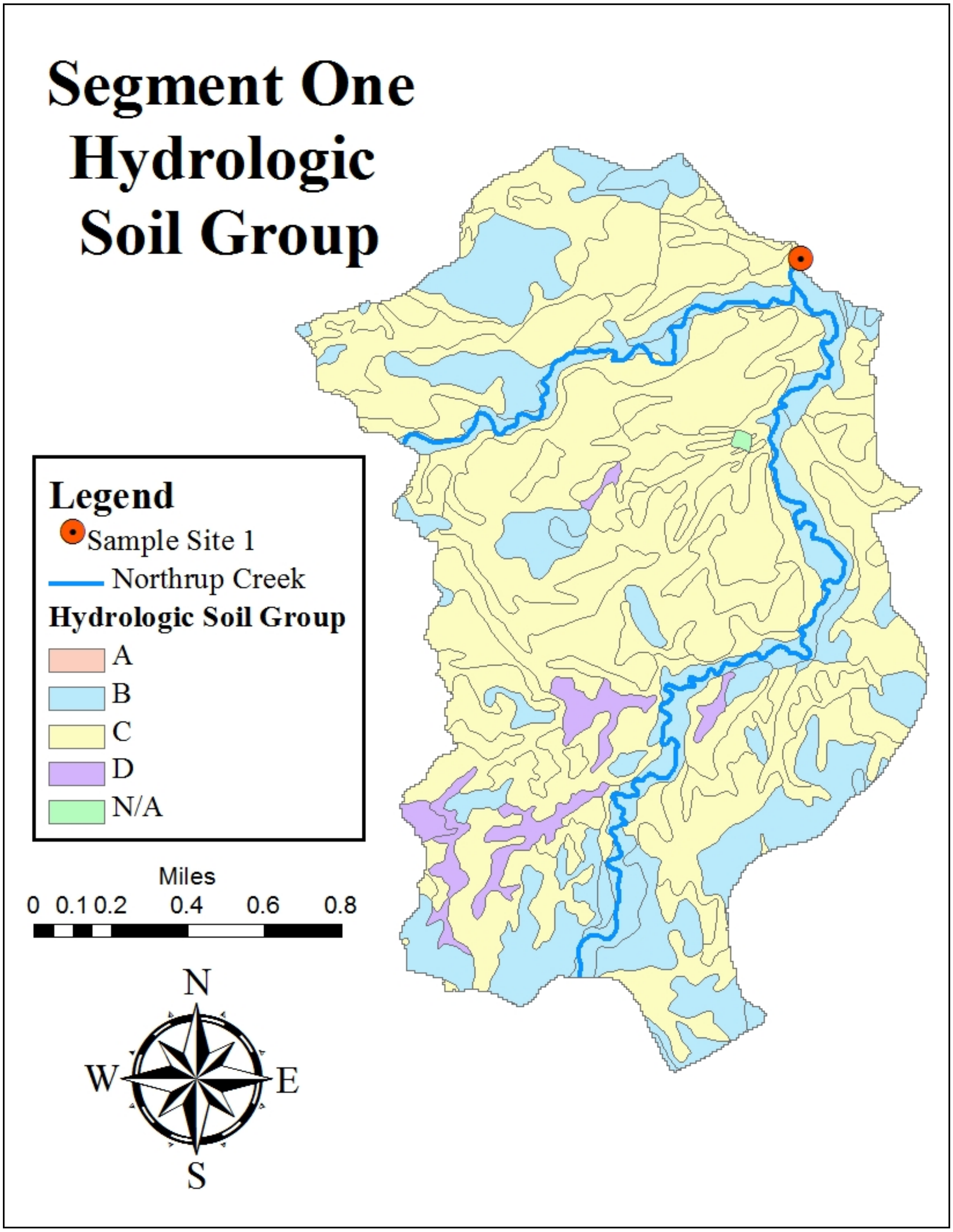
Appendix 5 cont.



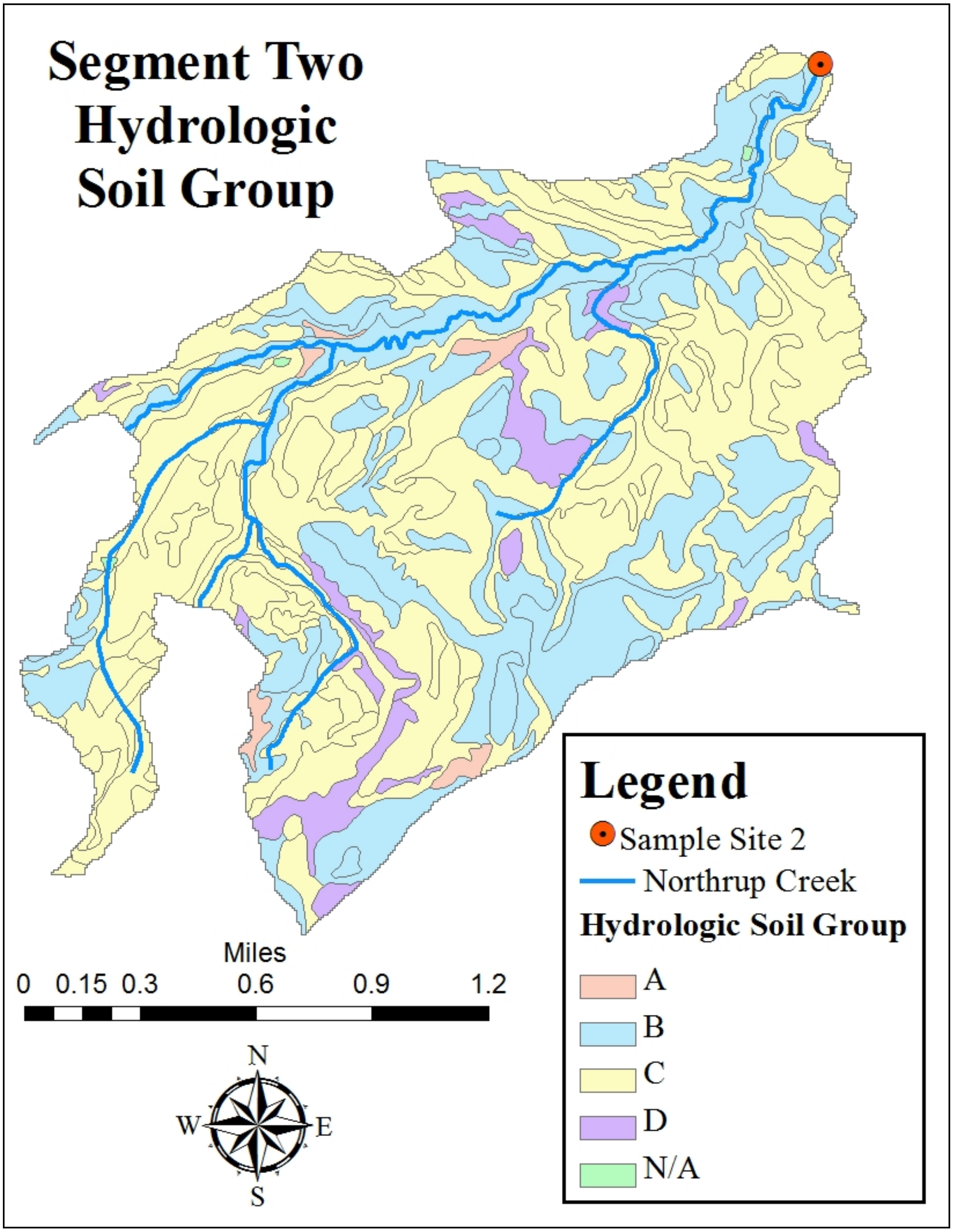
Appendix 5 cont.



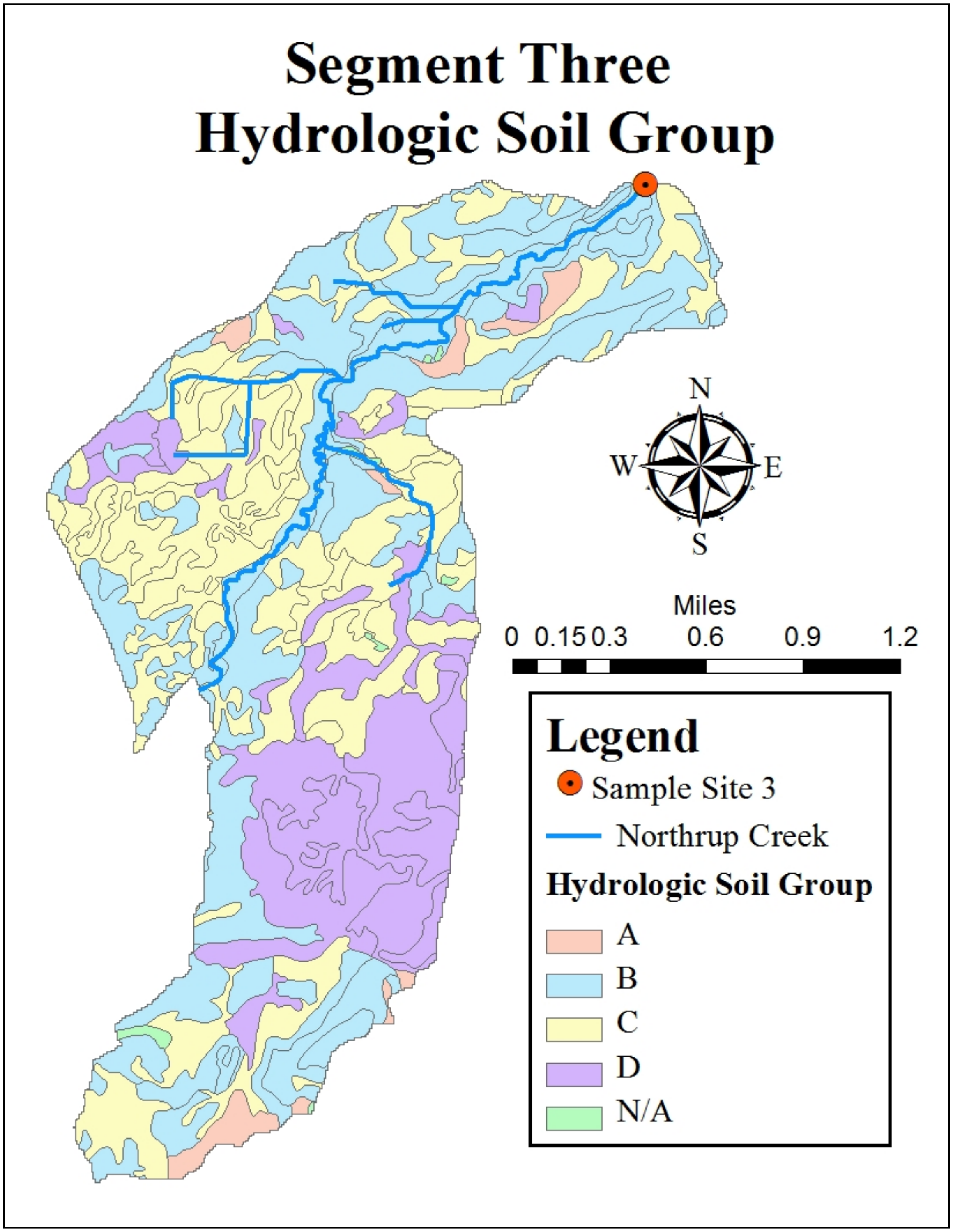
Appendix 6: Segmental soil hydrologic group maps



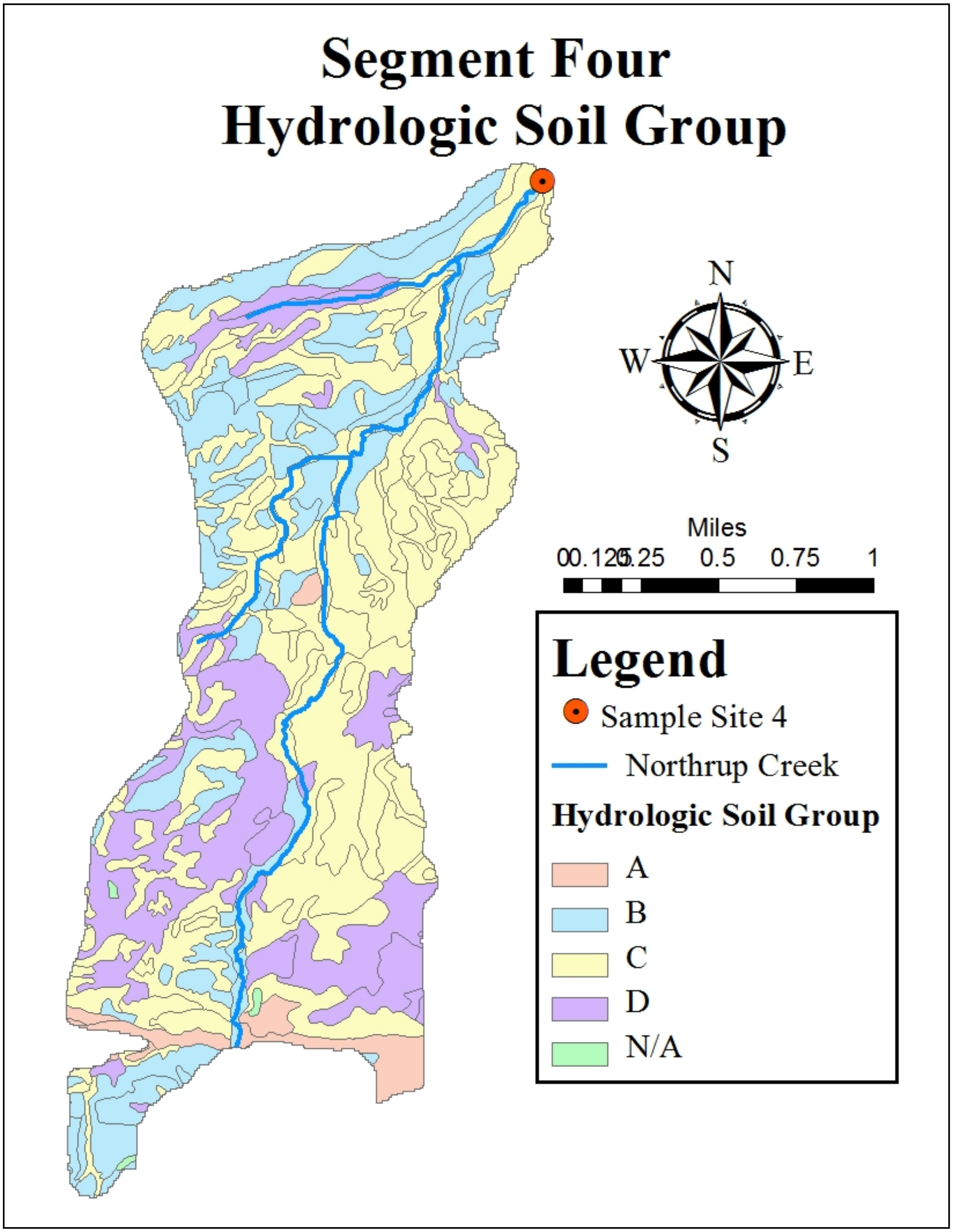
Appendix 6 cont.



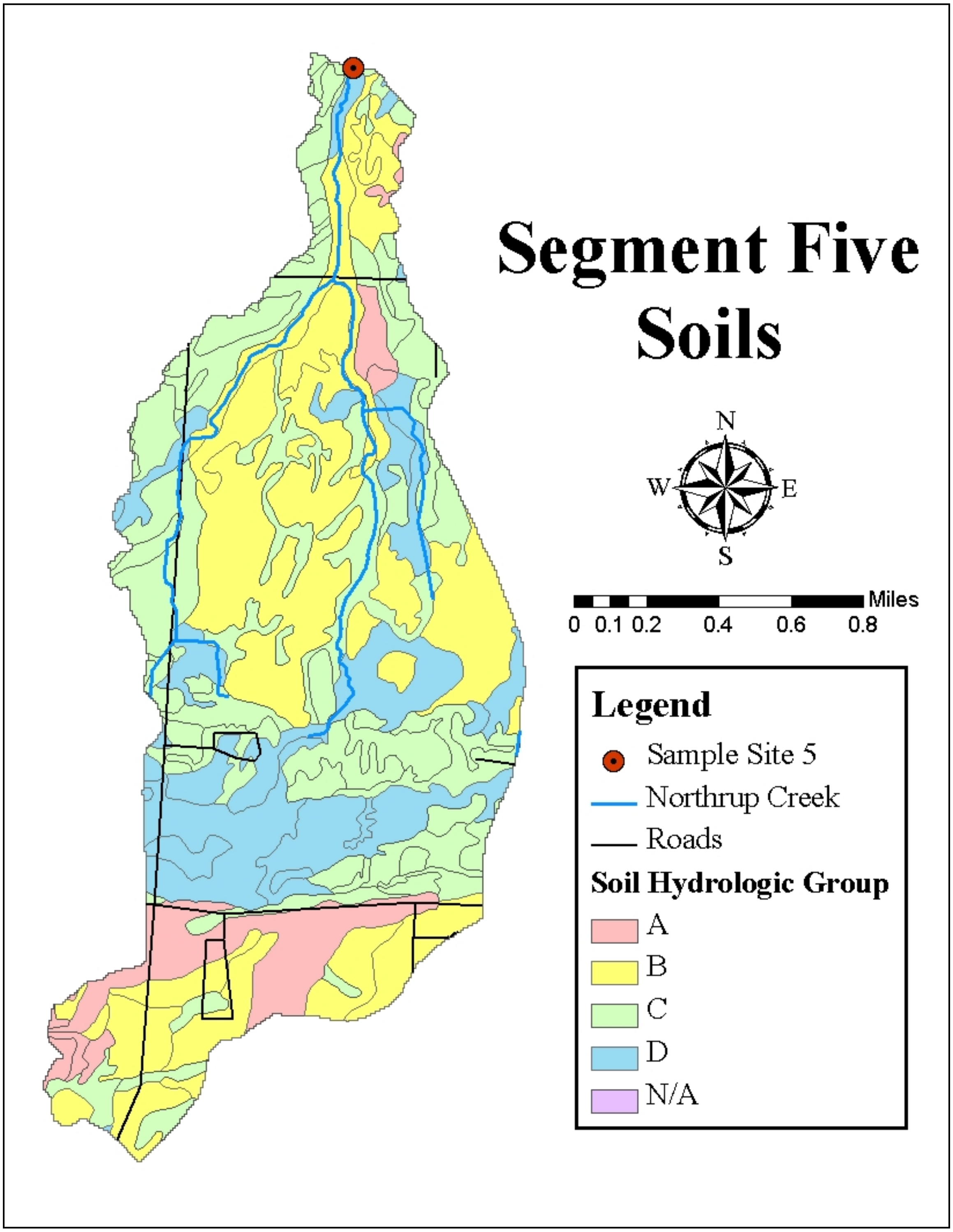
Appendix 6 cont.



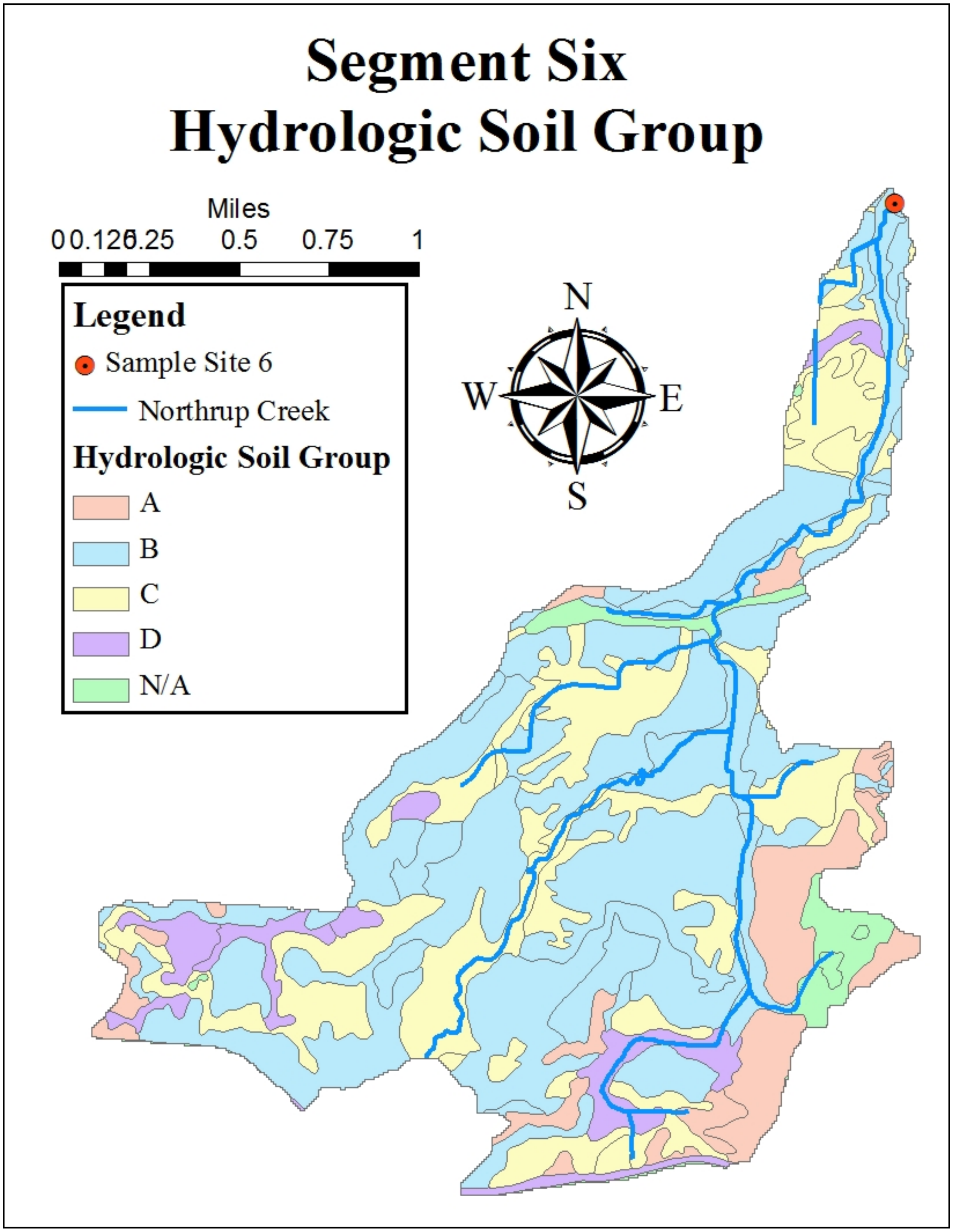
Appendix 6 cont.



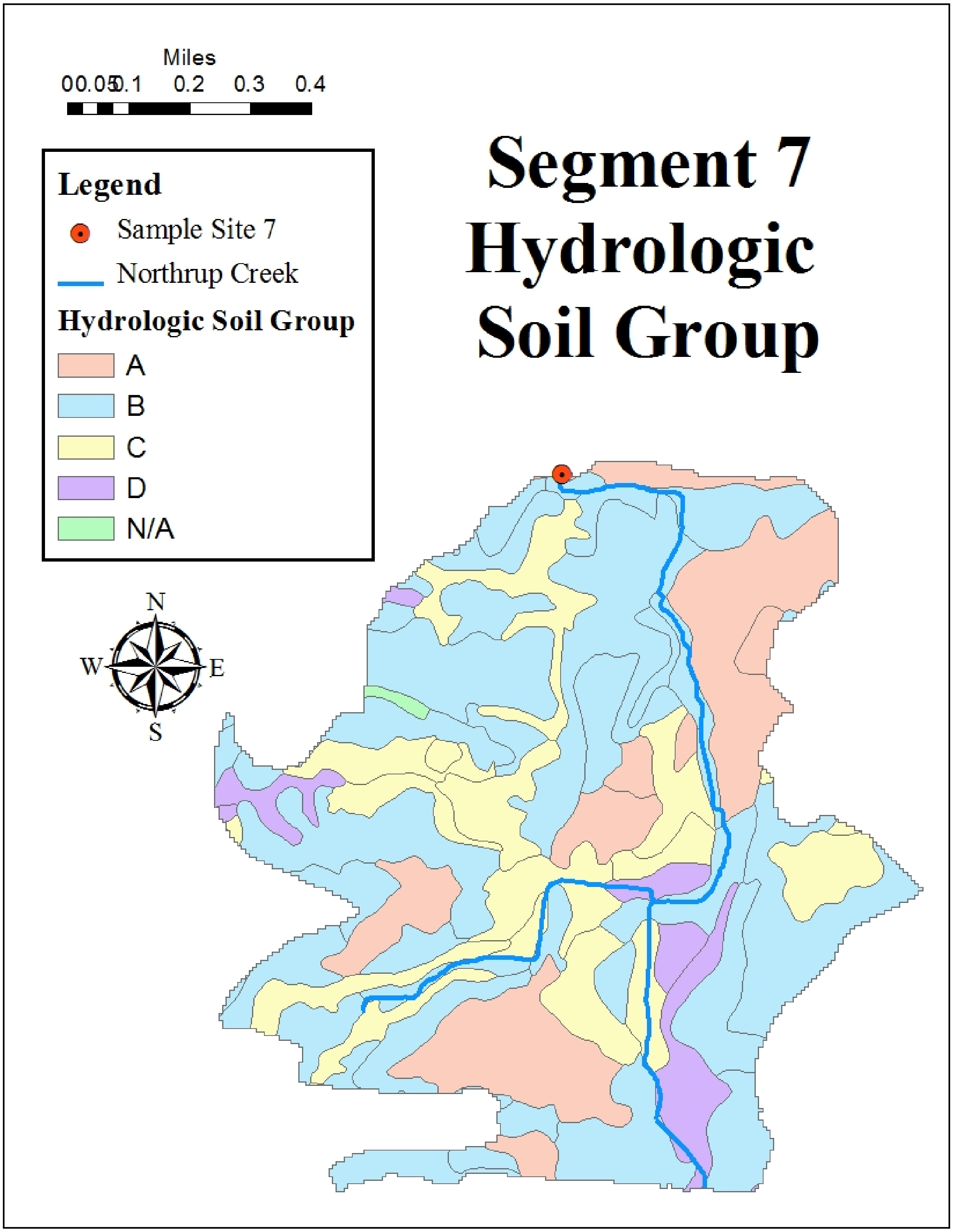
Appendix 6 cont.



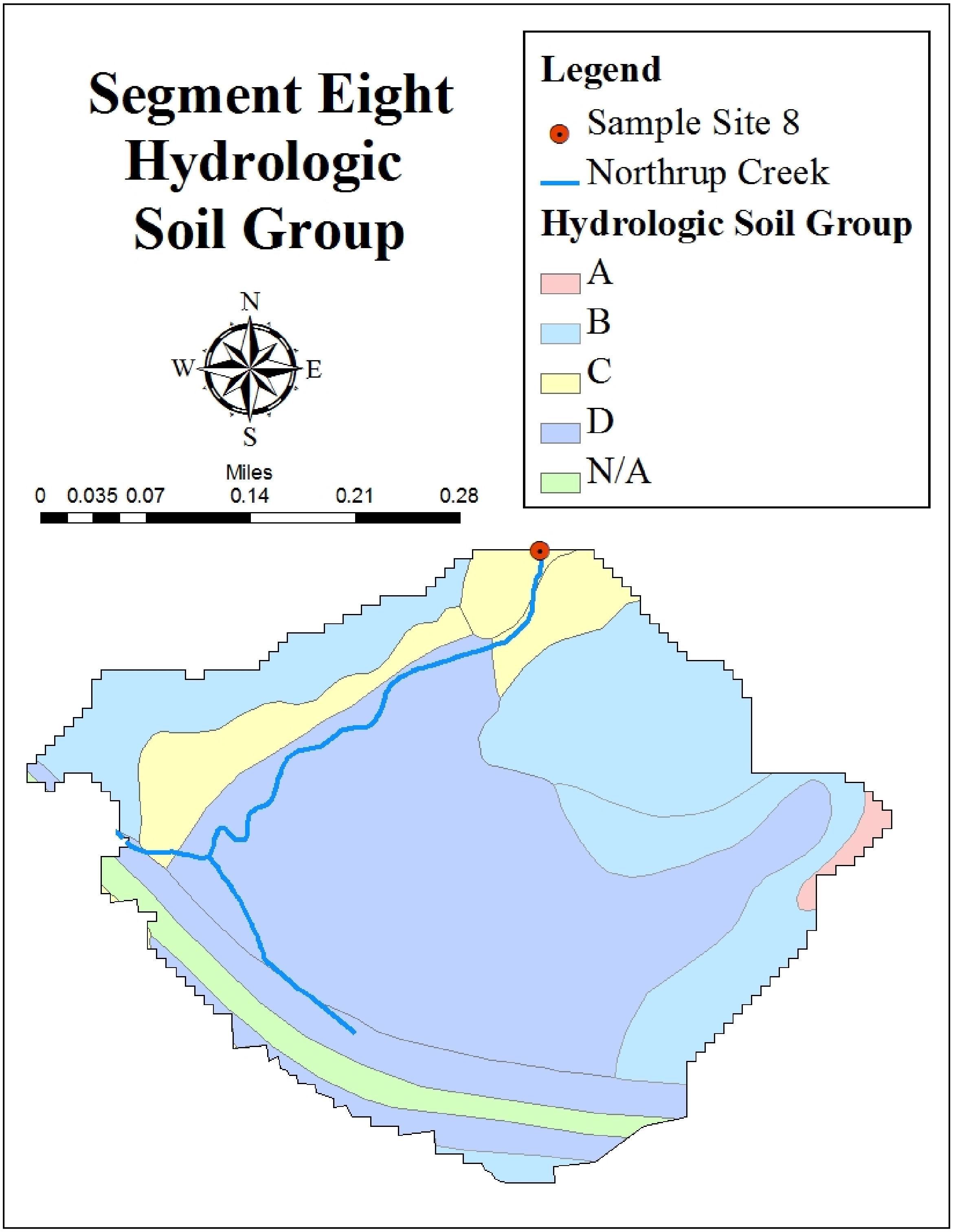
Appendix 6 cont.



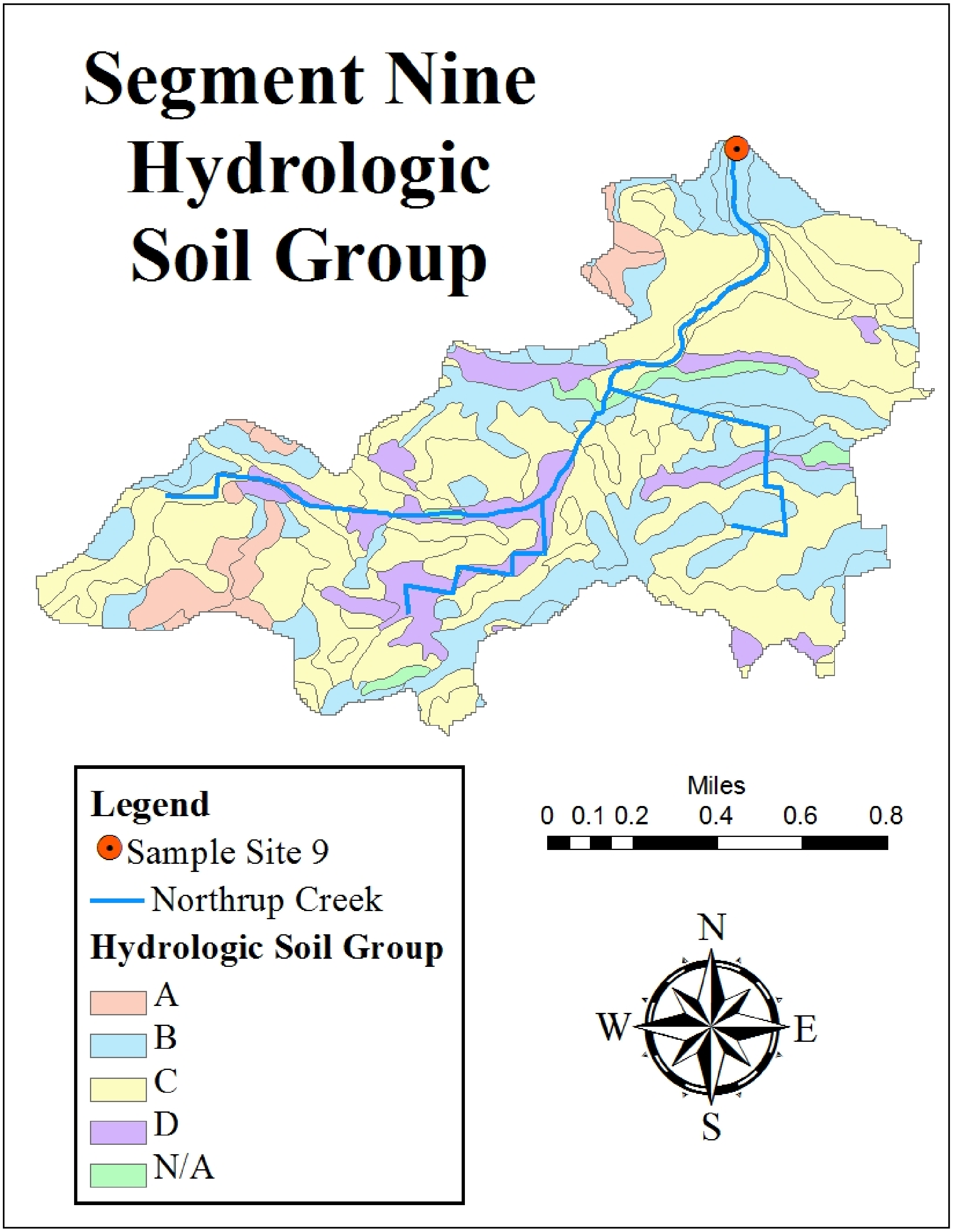
Appendix 6 cont.



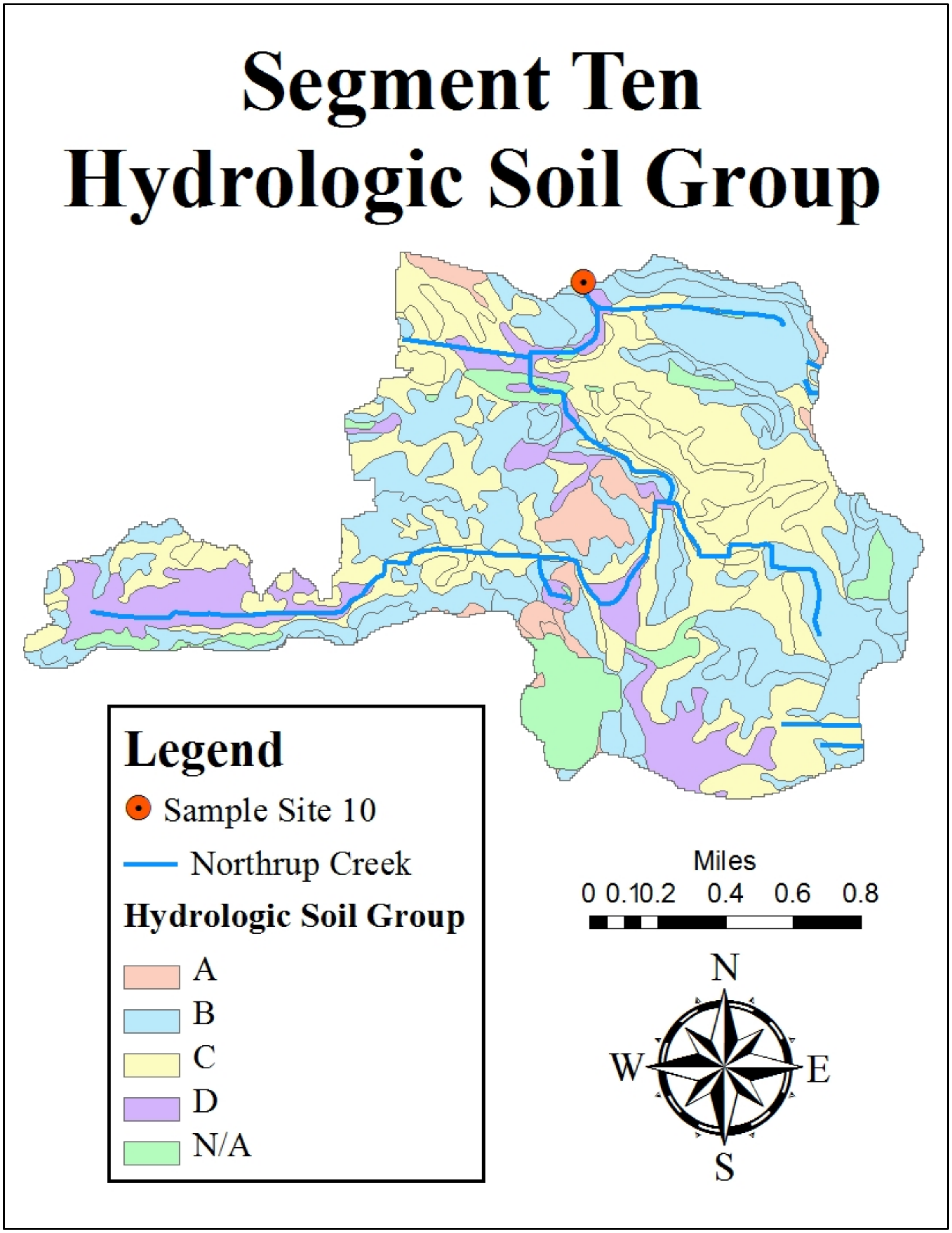
Appendix 6 cont.



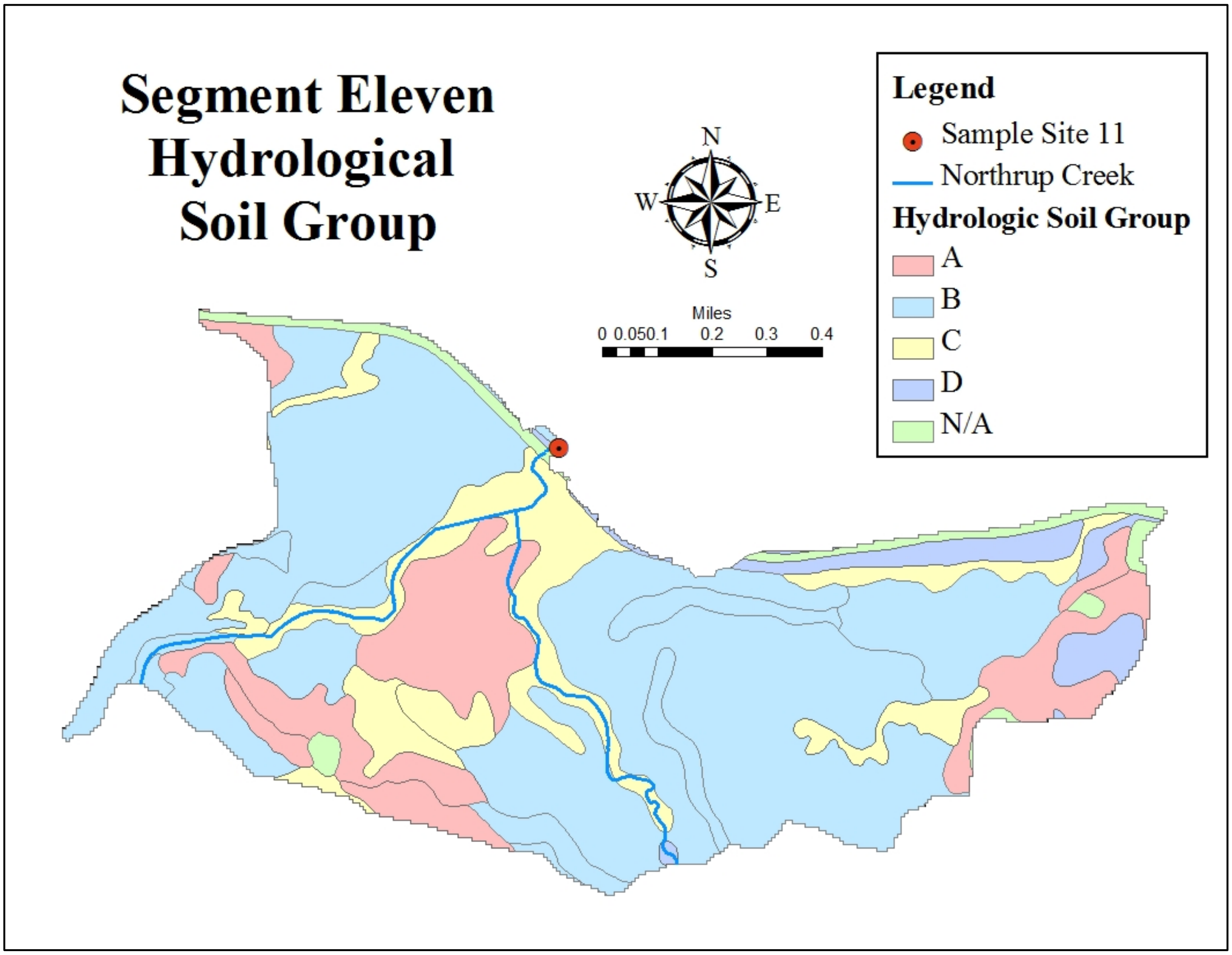
Appendix 6 cont.



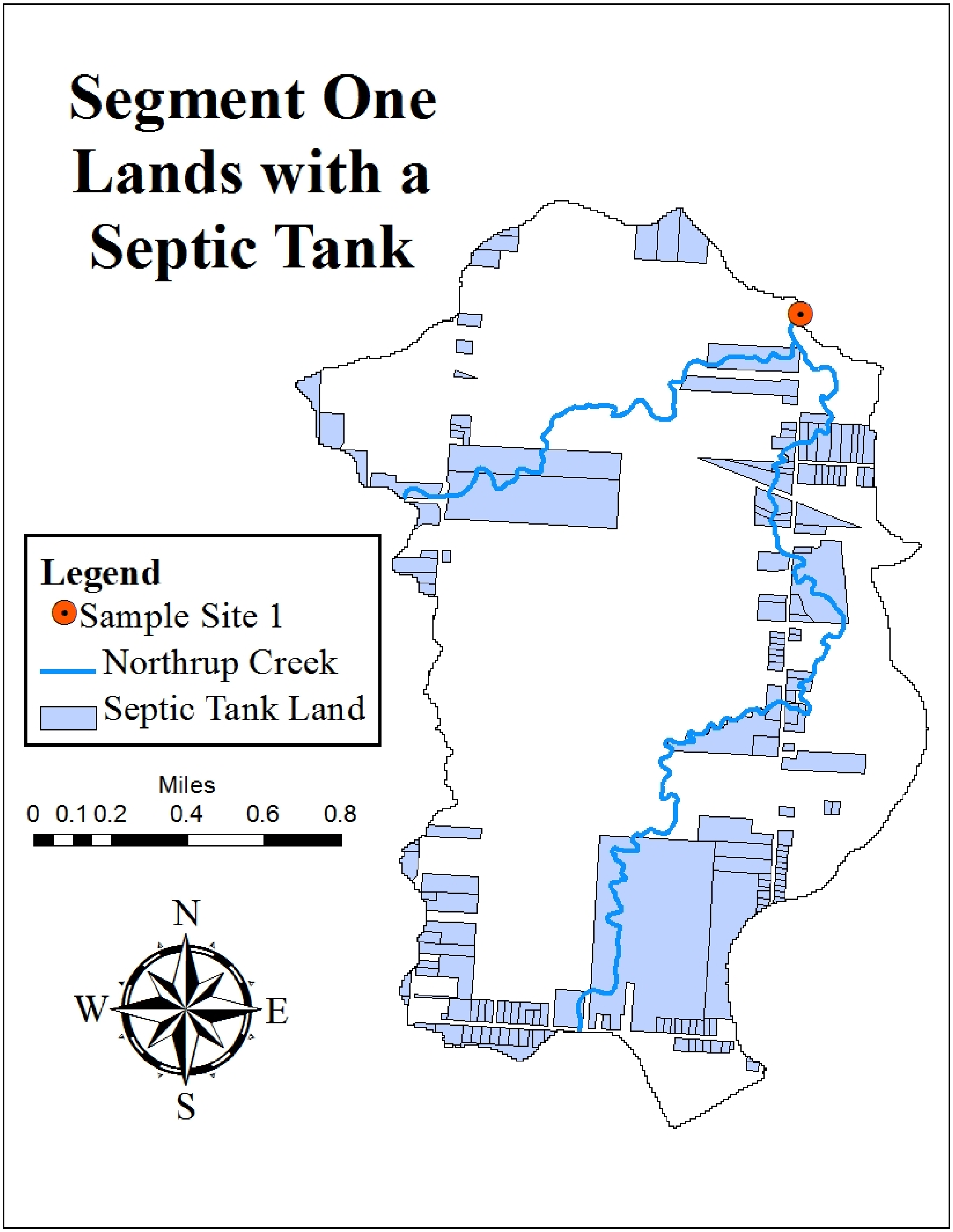
Appendix 6 cont.



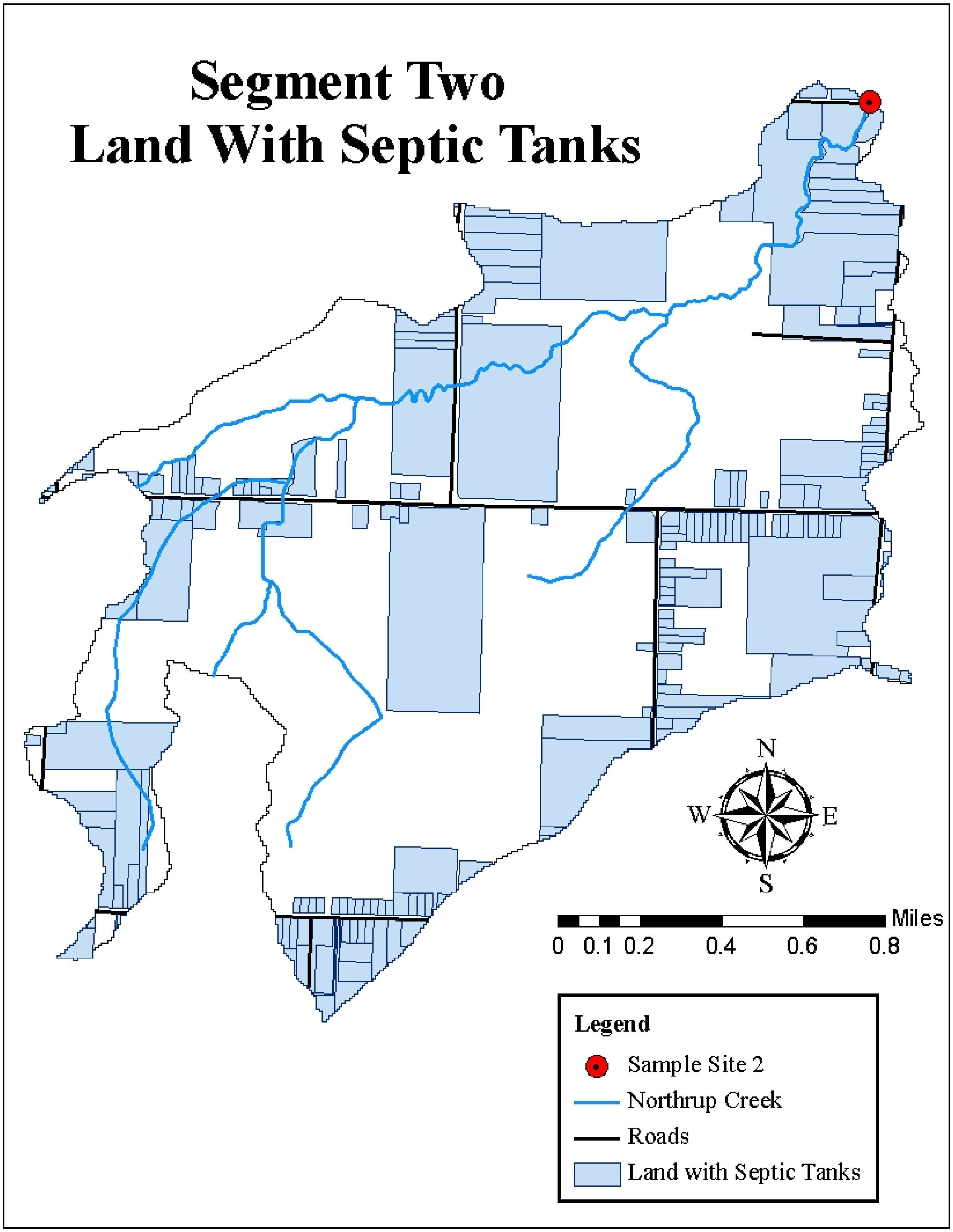
Appendix 6 cont.



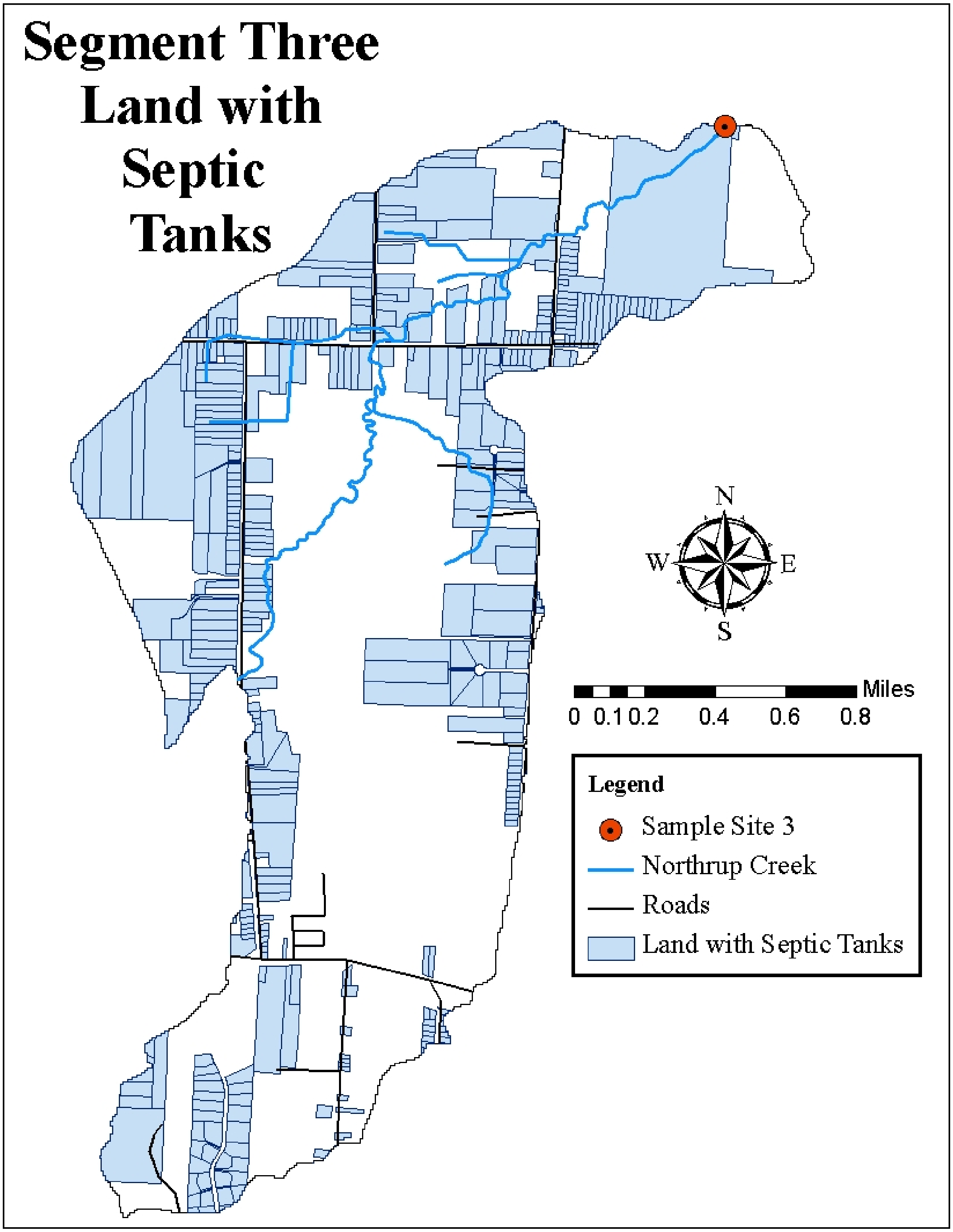
Appendix 7: Segmental septic tank parcel maps



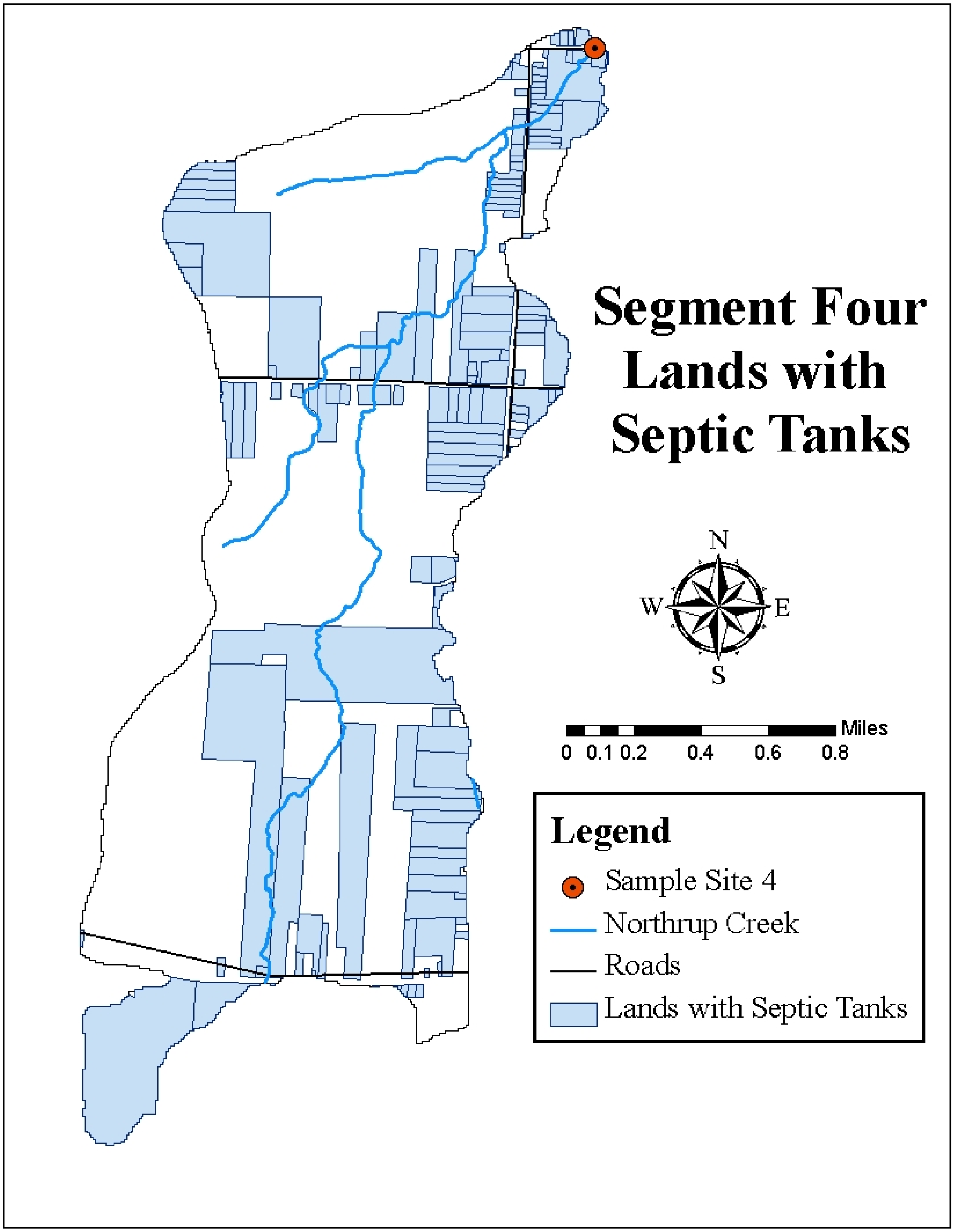
Appendix 7 cont.



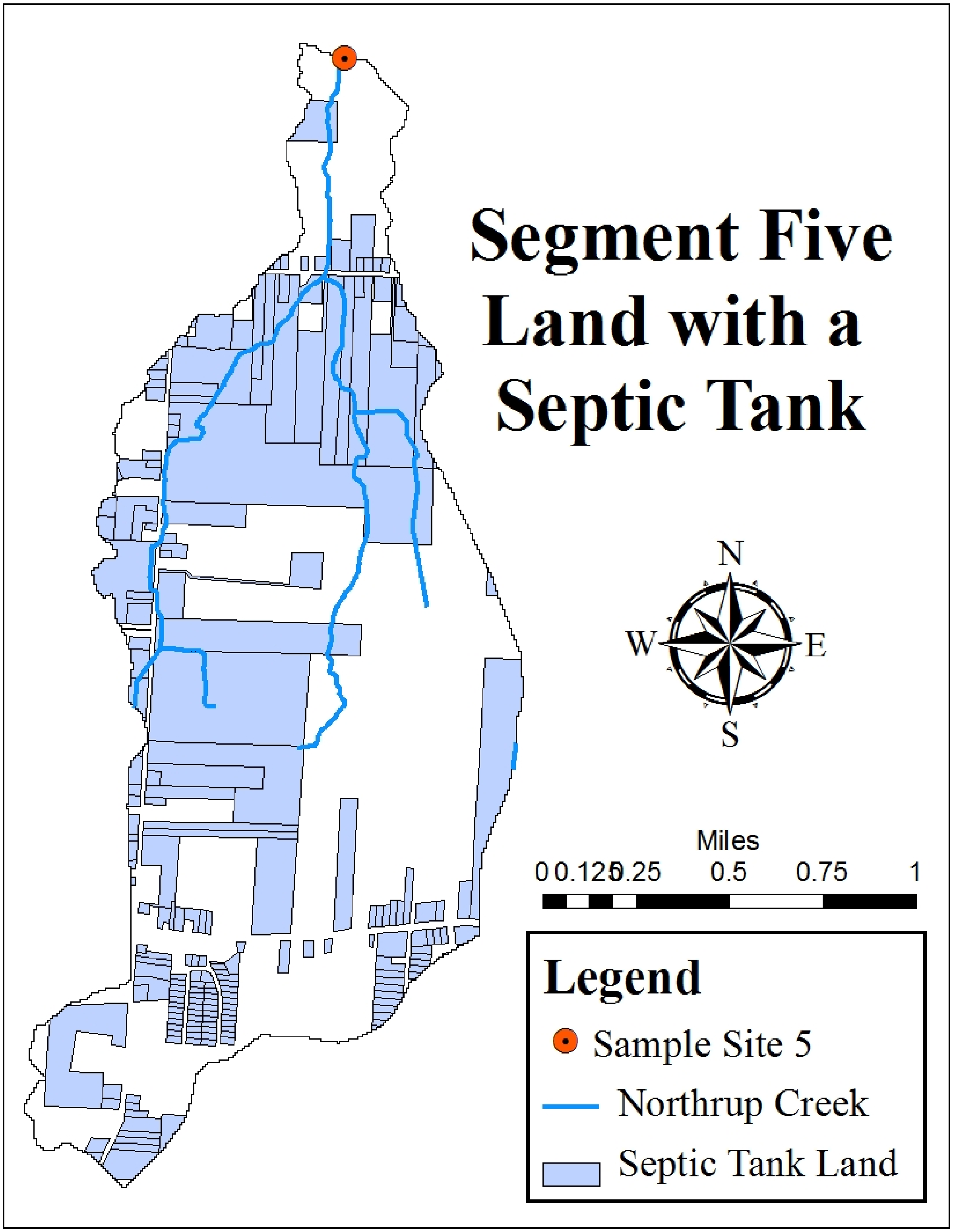
Appendix 7 cont.



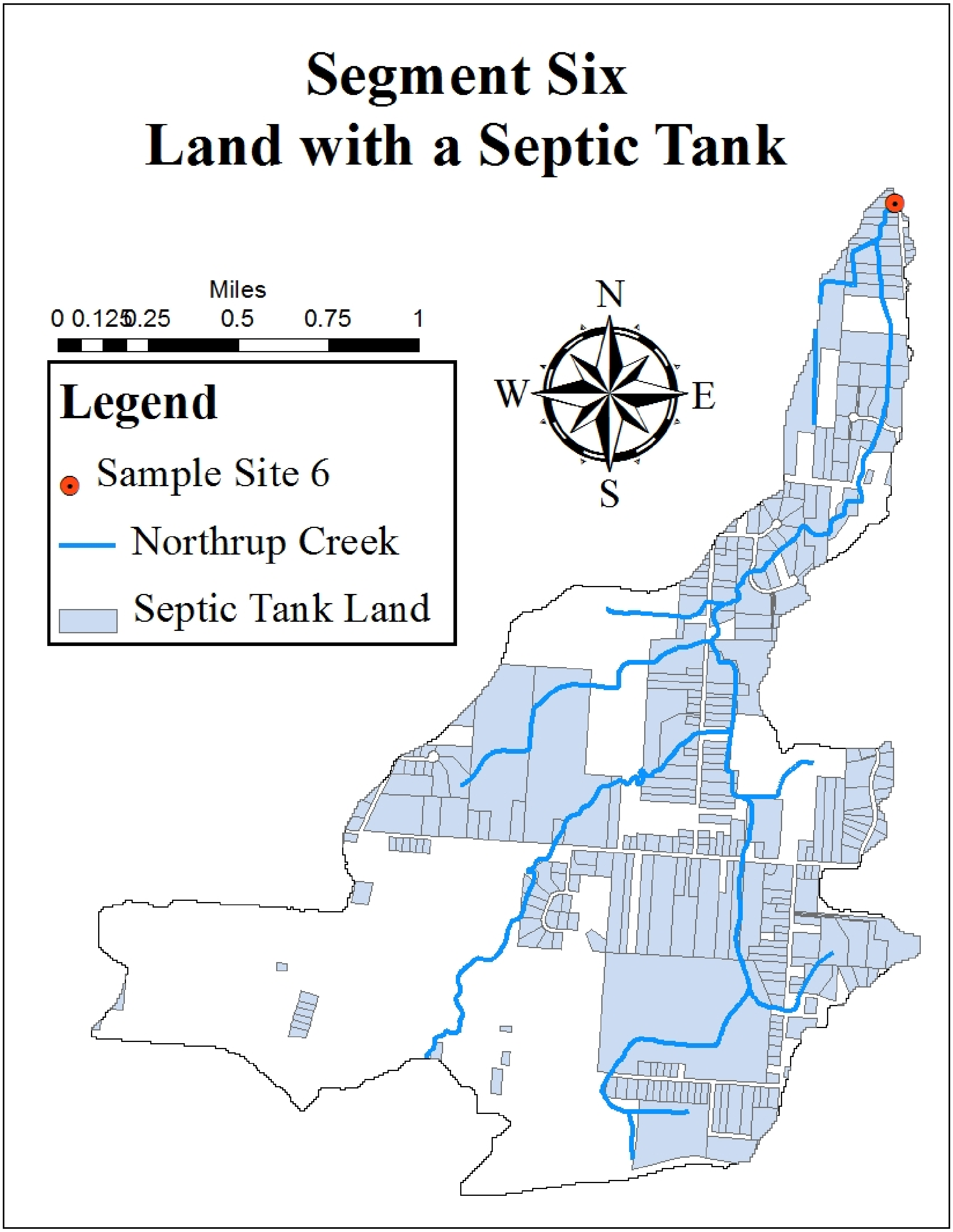
Appendix 7 cont.



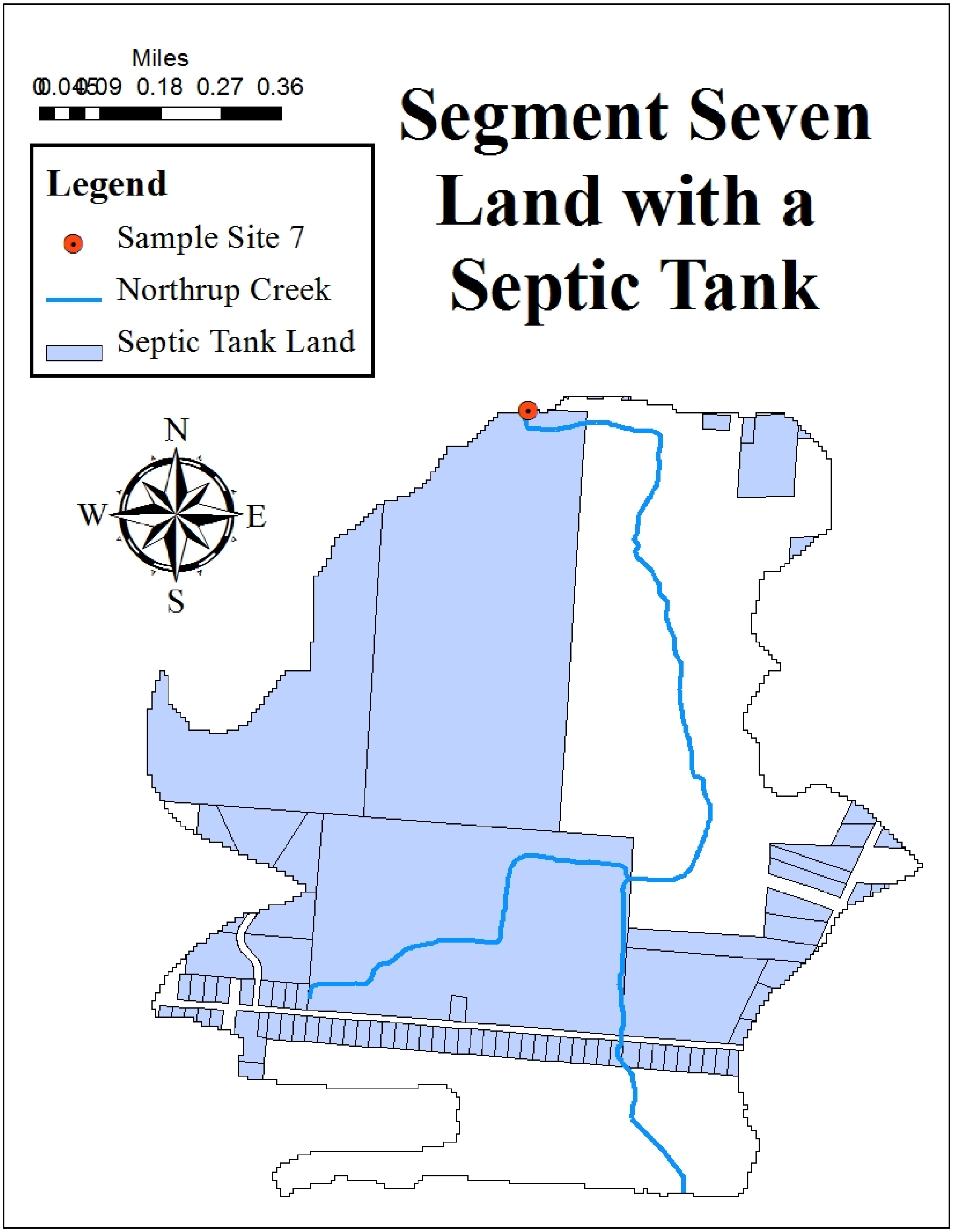
Appendix 7 cont.



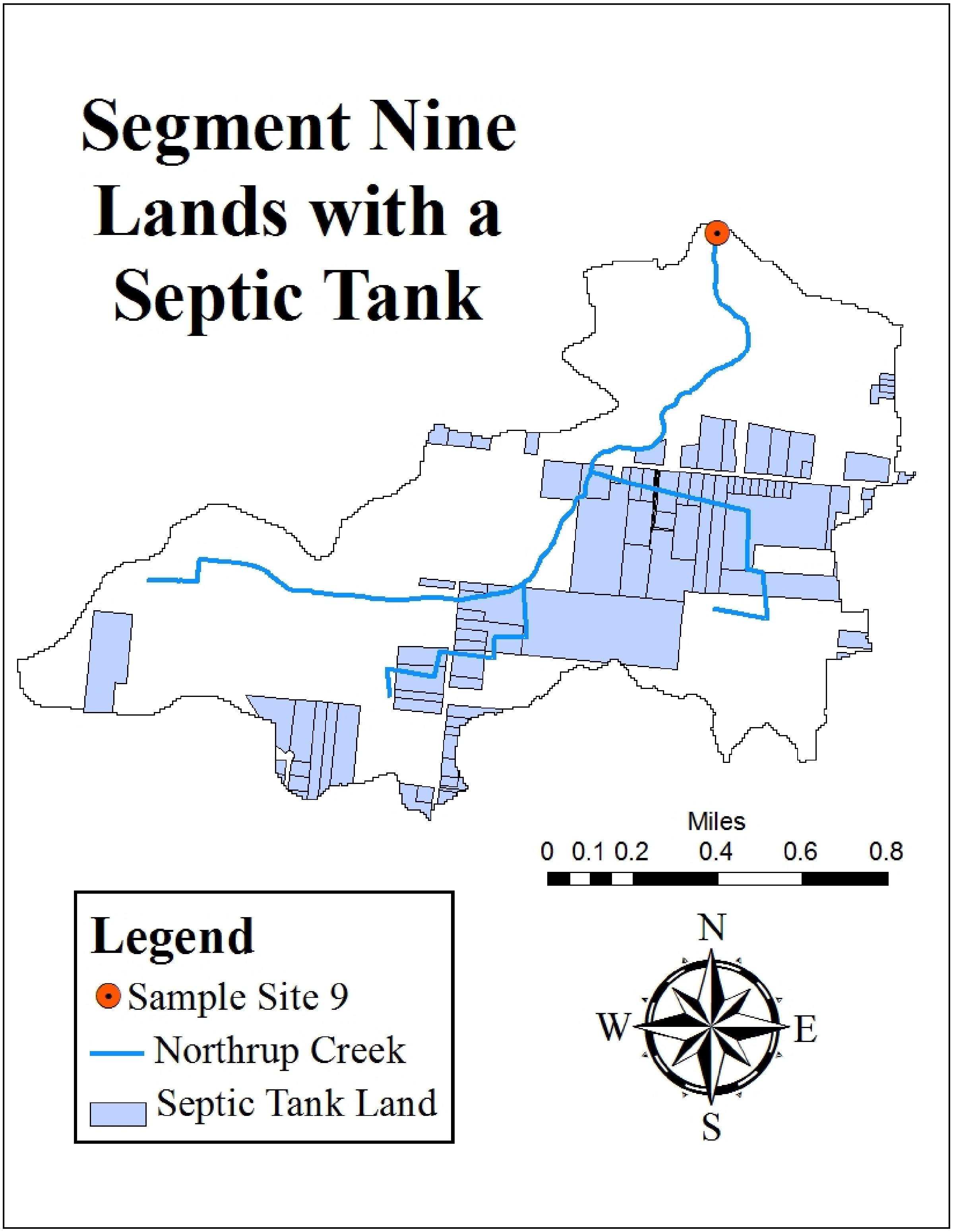
Appendix 7 cont.



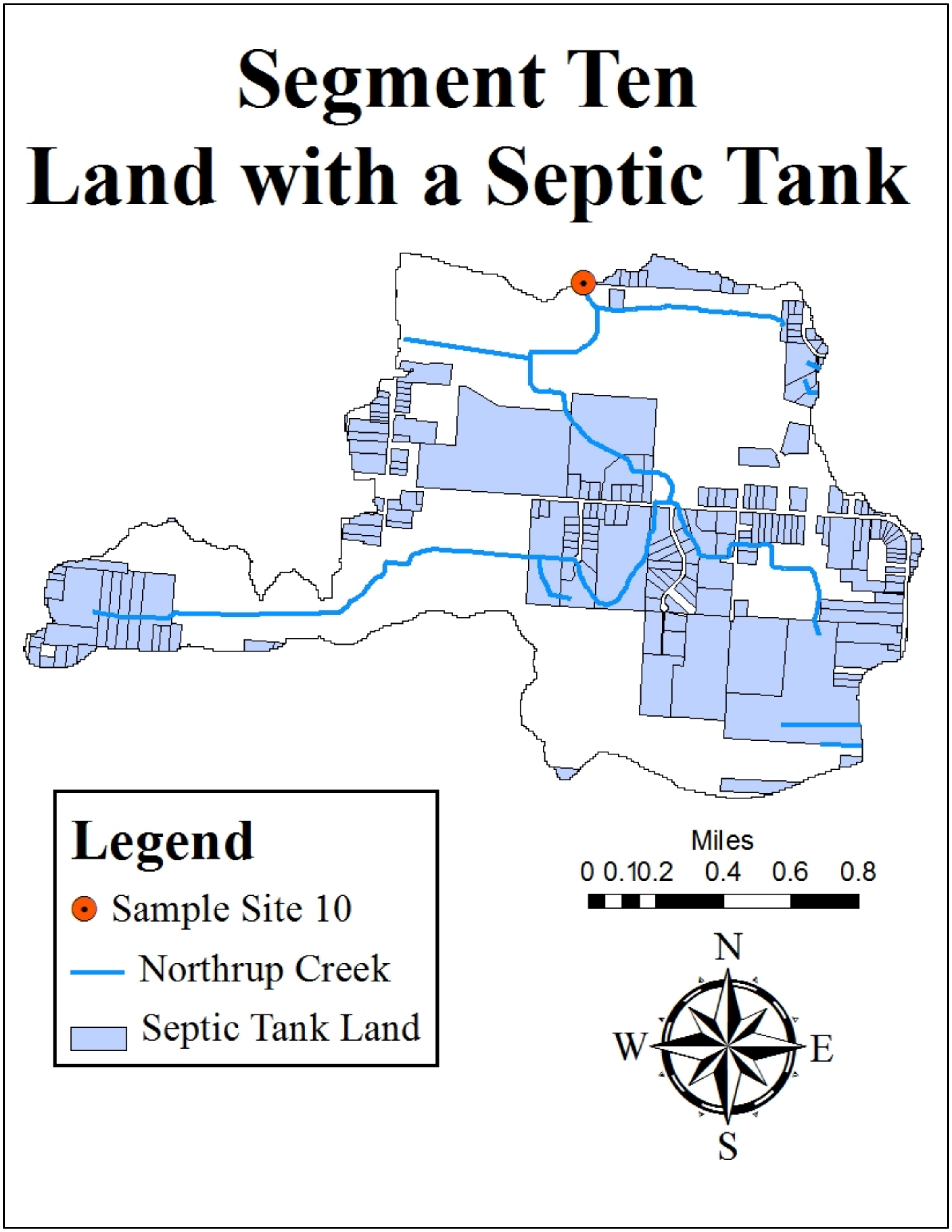
Appendix 7 cont.



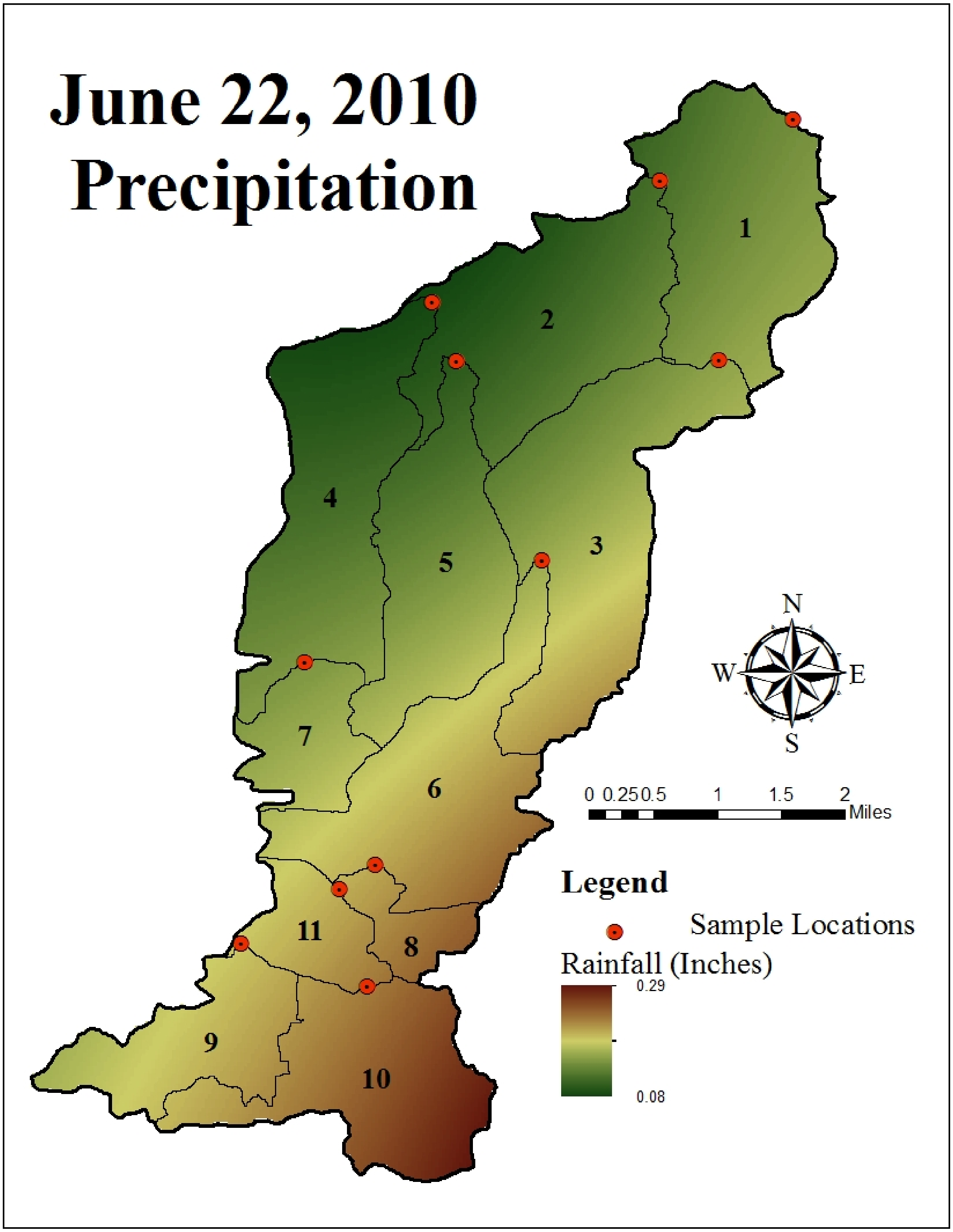
Appendix 7 cont.



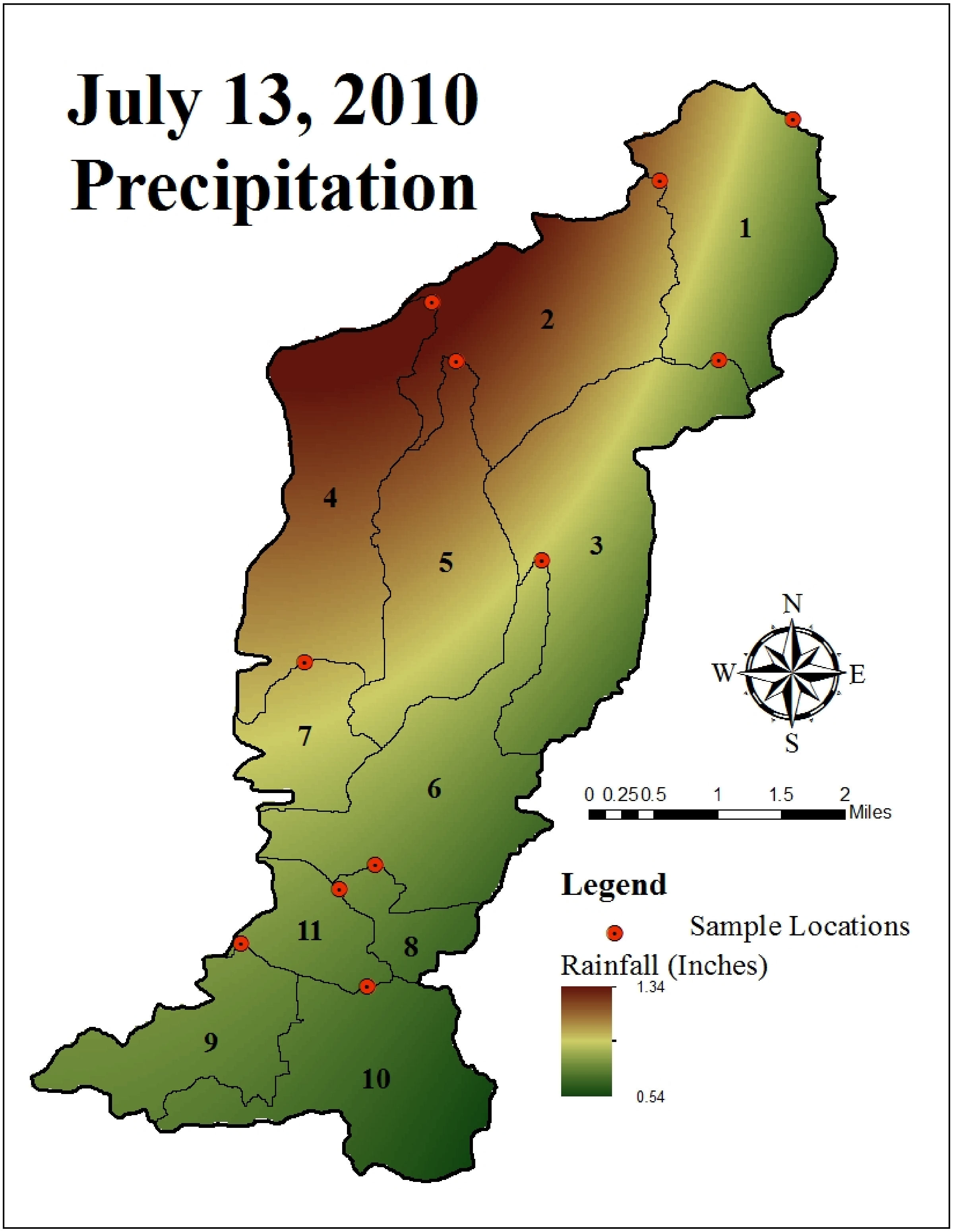
Appendix 7 cont.



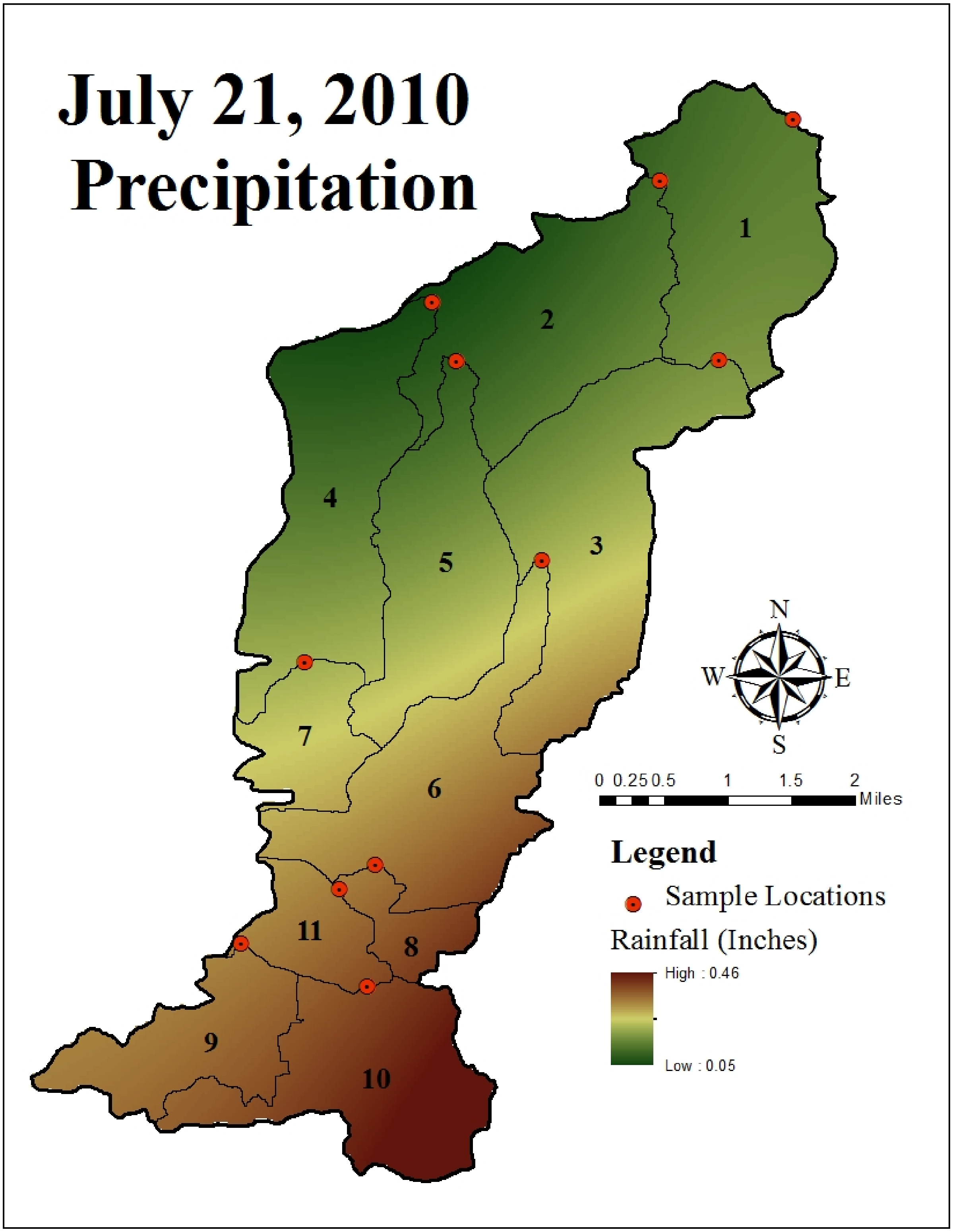
Appendix 8: Storm event precipitation maps



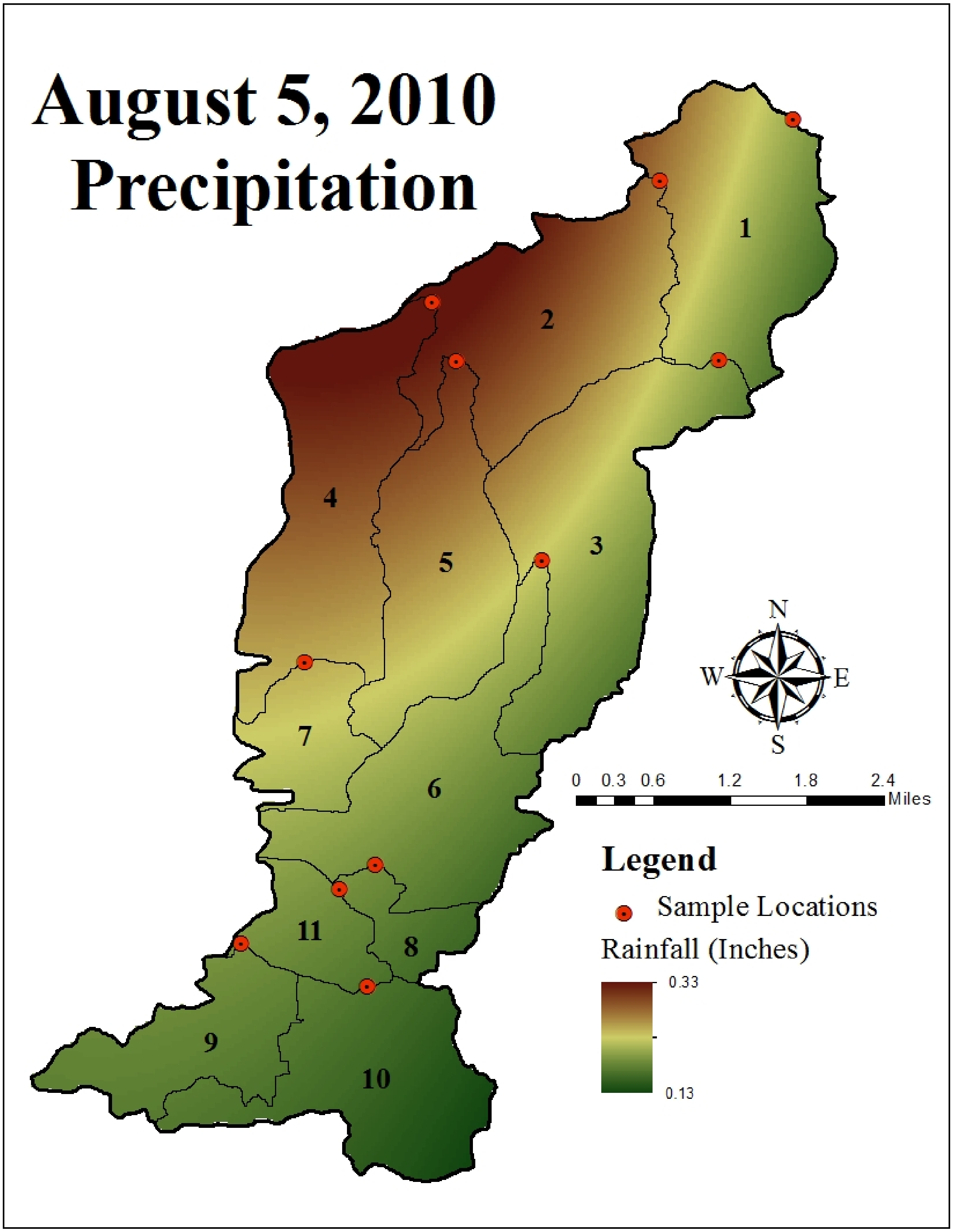
Appendix 8 cont.



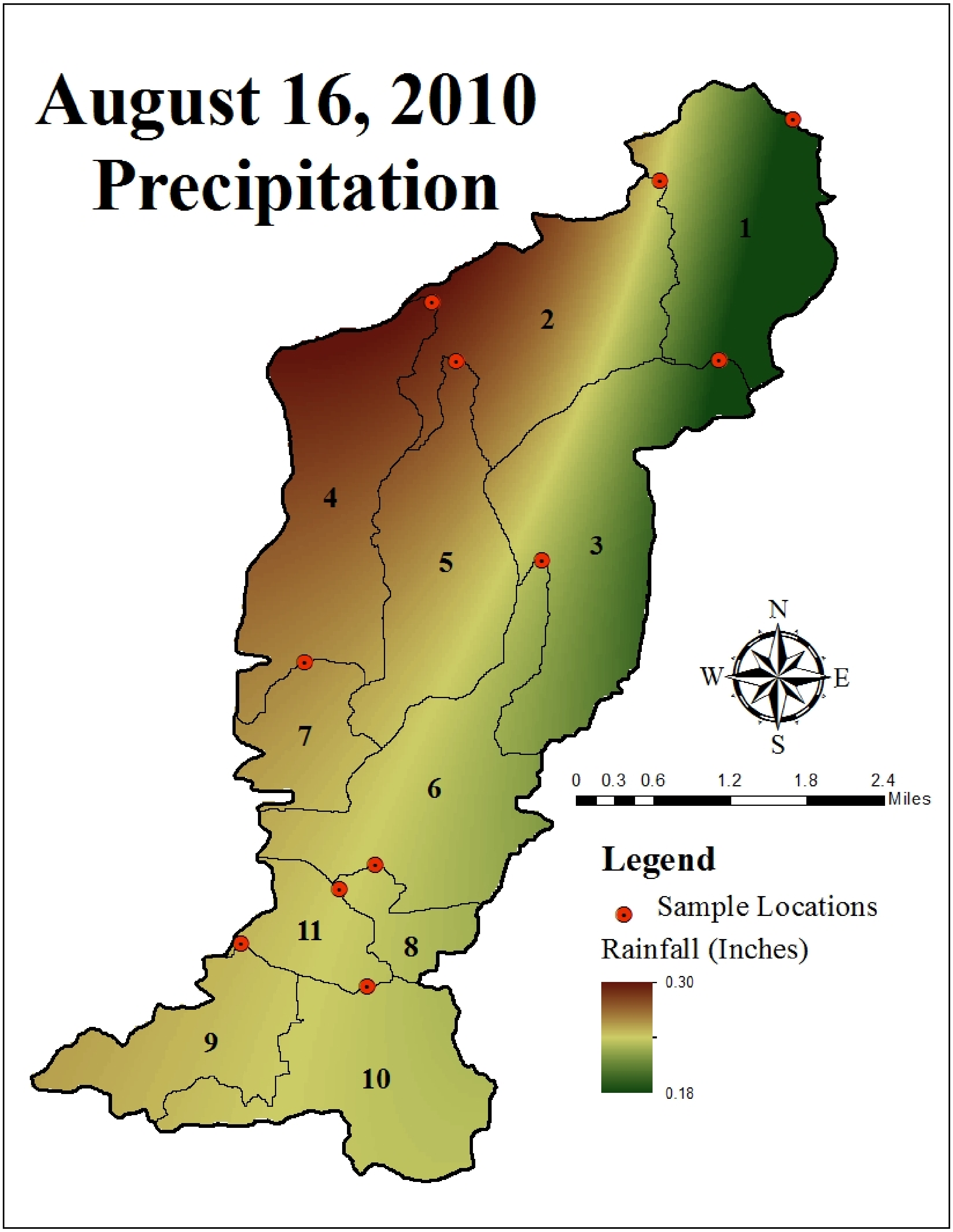
Appendix 8 cont.



Appendix 8 cont.



Appendix 8 cont.



Appendix 8 cont.